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ECONOMIC GEOLOGY

VOL. XX. MARCH–APRIL, 1925. NO. 2

THE CAMP BIRD COMPOUND VEINDIKE.

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INTRODUCTION.

As a gold mine that has been extraordinarily rich and profitable, the Camp Bird in Colorado warrants attention, and interest in its geology. Now that it has closed down, probably forever, it is of advantage to science to record some further[1] notes as to the occurrence of the ore, before its glory shall quite have faded into the past. The conclusions stated below were the result of careful instrumental geological surveys,[2] and repeated examinations.

The mine is in the Ouray district, and was located by Thomas Walsh in 1896, and operated by him till 1902, when it was sold to an English company, the Camp Bird Limited, who operated it till its ores were exhausted. It practically closed down in 1916, though development work was carried on until within two or three years. It produced many millions of dollars, and yielded many millions of profits, being during its best period one of the well known gold mines of the world. Sic transit gloria mundi.

ROCK FORMATIONS.

The geology of the San Juan Mountains, in a section of which the mine lies, need not be gone into here. It has been well de-

[1] The Camp Bird vein has been discussed by C. W. Purington (*Trans. A. I. M. E.*, vol. XXXIII., 1903, pp. 499–528); by F. L. Ransome (Bull. 182, U. S. G. S.); and H. A. Titcomb, *Columbia School of Mines Quarterly*, N. Y., Nov., 1902.

[2] The geological work was done mainly by myself and J. H. Farrell.

scribed in the publications of the United States Geological Survey. These mountains represent a domical uplift,[8] probably due to the pressure of magma up from below; and smaller parasitic domes occur as details on the main dome. Due to the uplift, erosion has been swift and deep and has cut down through a great range of formations.

Starting at the town of Ouray for the 8-mile ride up to the Camp Bird mine, one passes through Paleozoic limestones and sandstones and through sandstones and conglomerates of the Mesozoic, amounting to several thousand feet, to where a thin

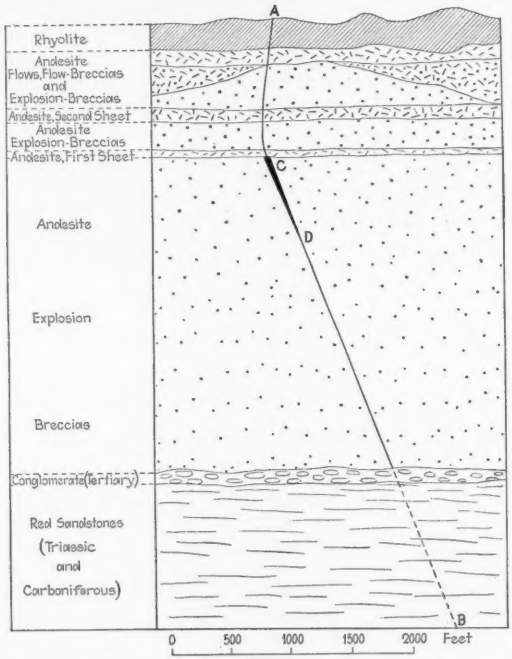

FIG. 15. Camp Bird vein and enclosing rocks. AB, Camp Bird vein; CD, productive portion of same.

[8] F. L. Ransome, Rico. Folio, U. S. Geol. Surv., No. 130, 1905, p. 7.

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early Tertiary conglomerate overlies the Mesozoic (Triassic) red beds unconformably. (Fig. 15.) Then comes a vast accumulation from Tertiary volcanic outbursts. Explosive eruptions rapidly piled up over 2,000 ft. of andesitic breccia, containing angular fragments of andesite of all sizes, imbedded in finer-grained andesitic material, with only a rude layering such as would naturally arise from its accumulation under the open sky. (Fig. 16.) As seen underground, the fragments are typically

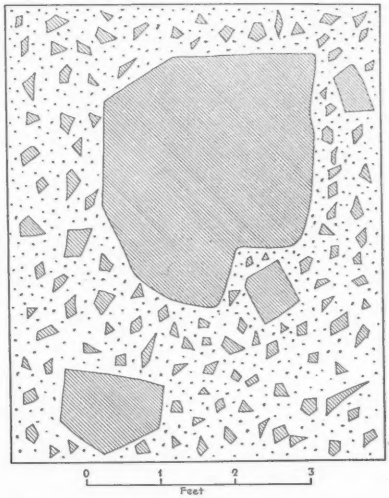

FIG. 16. Sketch of Andesite Breccia (Angular Green Fragments in Fine Red Matrix) showing Explosion Origin. Camp Bird Mine.

green, and the matrix is red, a striking contrast, showing that much of the fine material became oxidized during the process of expulsion and accumulation. Near the vein, however, the red matrix is turned green, so that fragments and matrix are difficultly distinguishable. These breccias accumulated to the great thickness of about 2,600 ft. with little or no change of character.

At the top of this comes a sheet of andesite only about 50 ft.

thick; above this sheet explosive andesite breccia entirely similar to that below comes in again for 200 or 300 ft.; and above this another andesite sheet, like that below, is encountered, this being upward of 150 ft. thick. Then comes about 500 ft., more or less, of andesite explosive breccias (some of them differing slightly from the thick explosive breccias beneath) with flow-breccias and andesite flows. Then come rhyolite flows, the uppermost formation of all. The maximum thickness of this rhyolite shown above

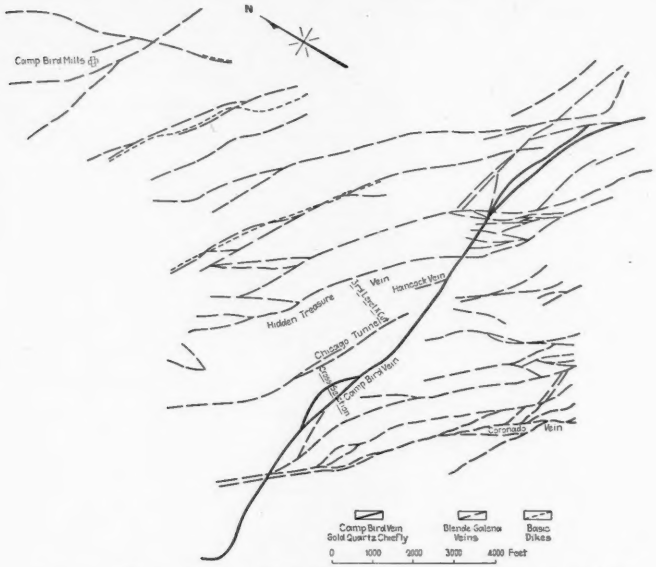

FIG. 17. Map of Camp Bird Vein and other veins in the vicinity.

the mine, or in the immediate vicinity, is about 600 ft. The total thickness from the bottom of the rhyolite down to the first andesite flow is about 900 ft. These rock distinctions should be borne well in mind, since they play a major rôle in the localization of the ore of the Camp Bird mine.

Erosion accompanied these volcanic accumulations, especially

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the later ones, so that toward the end the flows or breccias were laid down upon highly accidented erosion surfaces. This explains why the thickness of volcanic accumulations in Figs. 18 and 20 (actual sections) is less than the maximum shown in Fig. 15.

The last lava emission consisted of a few straight parallel basic (andesitic) dikes. These have a nearly due northwest course, which is also the course of nearly all of the numerous mineral veins in the section—but not of the Camp Bird vein, which is a marked exception, as will be shown. (Fig. 17.) Indeed these northwest veins came up along the same set of fissures as the basic dikes, so that they in several instances run along the side of such dikes, or even split them and run down their middle; but the veins are far more numerous than the dikes.

THE CAMP BIRD VEIN.

The Camp Bird vein, the most notable one of the immediate vicinity, has an average direction only a little north of west, so that it cuts across the strike of nearly all the other veins at an angle of 45 deg. or so. It is not straight, but curves and wobbles, as the other veins do also, but to a less degree. Its extent is very persistent along the general strike, and has been mapped by myself and assistants, for nearly five miles as shown in the figure (Fig. 17); and this is probably far from being the total length. It dips, normally, about 65 deg. to the south. When will some brilliant investigator explain to us just why veins usually dip 60 to 70 deg.?

ORE SHOOTS.

The productive stretch of the Camp Bird vein, however, is only a fraction of the distance mentioned, being about a mile in length. And in this distance the ore is not continuous along the strike, stretches of ore alternating with almost absolutely barren stretches. (Fig. 18.) Two of these stretches form the principal shoots—the Discovery shoot and the Bluebird shoot, each extending a thousand feet along the vein, and separated by 600 to 700 ft.

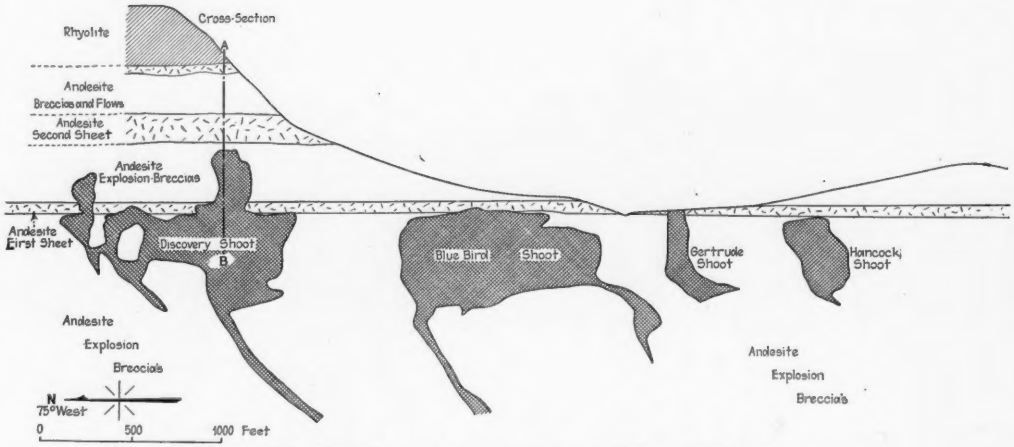

FIG. 18. Projection of stopes on plane of Camp Bird vein.

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of barren lode. West of the Discovery shoot there is practically no ore: east of the Bluebird there occur at intervals two shoots, with less extent along the strike—the Gertrude shoot, one or two hundred feet long, and the Hancock shoot, some two or three hundred feet long, which are separated from one another by a distance of five or six hundred feet.

The vertical extension of these shoots on this strong and steeply dipping vein was curious, and highly disappointing to the miners. This is best shown in the section on the plane of the vein. It will be seen on the projection of the plane of the vein (Fig. 18) that all the orebodies, *whatever the length along the strike of the vein, have about the same vertical extension,* which is, roughly speaking, 600 to 700 ft. or thereabouts: so that the longer shoots—the Discovery and the Bluebird—are longer than they are deep. All these shoots, it will be seen, moreover, have a flat top at almost precisely the same elevation, and a marked tendency to contract in length below that top, till they tail off downward like a turnip, the tail extending far down.[4] The vein itself continues with some strength in depth, but the ore shrinks in size and value till mining was not feasible. How deep the vein and spots of ore go I do not know. When I was at the property last (in 1910) the deepest workings were at an elevation (above sea level) of about 10,400 ft., or 1,500 ft. below the general top of the ore shoots, which general top is about 11,900 ft. Below this, andesitic breccia extends some 1,300 ft.; and in recent years a tunnel has been driven in at very much lower levels, and is reported to have found the vein, but no ore. Veins are found in other parts of this region also in the Mesozoic and Paleozoic rocks which underlie these Tertiary volcanoes; so that it is probable the Camp Bird fissure goes down through them also. The barren or low grade vein filling goes above the ore shoots and crops at the surface.

Some of these ore shoots, it will be observed, do not come to the surface at all; others have barely been exposed by erratic erosion.

[4] The reader, looking at Fig. 18, will perhaps wonder why all the "tails" tend to rake to the east. I do not know.

Here we have a case of pristine ore shoots, which have not undergone loss through erosion. The study of the peculiar limitations of these ore shoots is one which yields some definite results. The problem is resolvable into two elements—that of the horizontal distribution of the ore shoots; and that of the vertical distribution. Here is a vein traceable for over five miles—why does the ore have a total length of only about 3,000 ft. in separate shoots, all occurring in a stretch of vein less than a mile in length? Here is a vein which goes up to the surface, past the pay ore, and down in depth far beyond the limits of the pay ore—why the vertical restrictions?

Horizontal Distribution of Ore Shoots.—Taking the horizontal extension first, the horizontal maps of the vein in the ore-bearing section, show clearly that the *orebodies depend upon the local strike of the vein* (Fig. 19). The whole strike of the Camp Bird vein, as mapped on the surface, is about N. 70 deg. W.; the productive portion is about N. 77 deg. W. This productive portion is not straight, but zigzags along a succession of alternating stretches, of which one set strikes nearly east-and-west, and the other west-northwest (from N. 60 to N. 66 west, in different cases). This distinction is very important: the east-west stretches are typically barren, not only of ore but to a great extent of any vein material. Those stretches which become more northerly in strike (say N. 73 west, as in the case of the stretch near the extreme western end of the second level), show considerable amounts of vein-material; while those bearing still further north are the stretches marked by ore-bodies. The three principal ore-bodies on the second level, named in the relative order of importance, have trends of N. 60 W., N. 65 ½ W., and N. 63 W.; and the first-named, which is most northerly, is that of the widest ore-body—the Discovery.

The explanation of these relations is plainly that after the formation of the long zigzag fracture that initiated the vein, the rocks on the south side were shoved in a due westerly direction 15 or 20 ft. horizontally past the rocks on the north side. Where the movement was parallel to the fracture, as along the east-west

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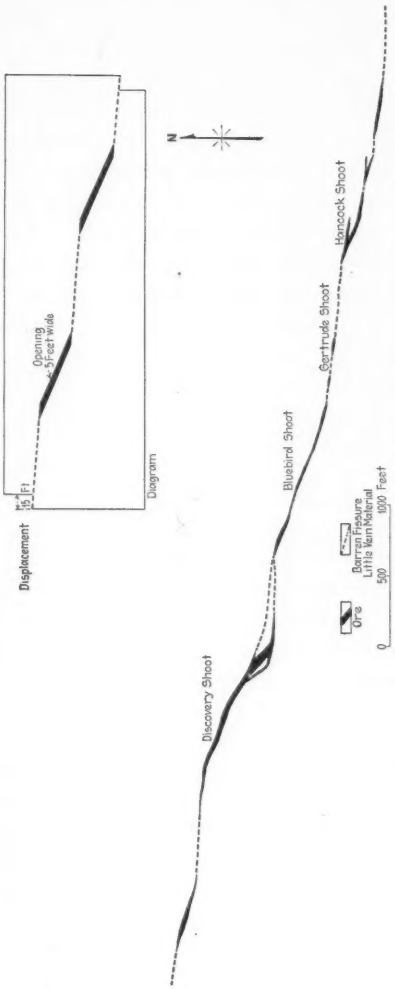

FIG. 19. Camp Bird vein, second level, showing different elements in strike.

stretches, no openings resulted; where the fracture was oblique to the movement, the walls were separated, leaving fissures. These fissures of limited extent along the strike became the channels for ascending metalliferous solutions or ore magmas.

It is obvious that in any vein whose *dip* alternates from steeper to flatter pitches, as does the *strike* of the Camp Bird vein, alternations of pay ore and barren vein might occur. Thus it might be the alternating steeper dips which would carry the most ore. In this case a slight relative sliding down of the hanging wall rock past the foot wall would have provided greater openness along the steep pitches and so induced the greater thickness of ore. If the foot wall slid down relative to the hanging wall, the ore shoots would be on the flat pitches.

This was pointed out long ago by Von Cotta; and Purington [5] referred changes in value of ore with change of dip, in the Camp Bird region, to this cause. Many examples of this in the Cornwall mines have been given by Collins; [6] and Mr. Bernard MacDonald has recently called attention to it in Mexico.[7] So far as I know, however, the case I describe is the first where the principle has been applied to *horizontal* alternations of ore and barren vein; although the extension of the explanation is obvious. Alternations of this sort on the dip are due to the vertical differential movement; such alternations on the strike are due to horizontal movements. Moreover, had the direction of the horizontal movement on the Camp Bird been to the east on the south side, the east-west stretches would have become ore shoots instead of the reverse, which actually happened. On the third level

[5] Purington, C. W., U. S. Geol. Surv. Telluride Folio, 1899, p. 16.

[6] Collins ("West of England Mining Region," *Trans. Royal Society of Cornwall*, 1912, pp. 121–122) quotes Capt. Charles Thomas' opinions that in many veins of Cornwall "changes in the bearings of the lodes appear to be the chief cause of productiveness or otherwise." "His remarks, however," observes Mr. Collins, "do not so much relate to the small "turns" and "warps" as to the larger inflexions often met with, when, for instance, the mean bearing of the lode being E. 22 deg. N., the bearing of the rich parts is more commonly east and west, and that of the poor parts is much further from east and west." No explanation for this condition is offered.

[7] *Eng. and Min. Jour. Press*, Vol. 117, p. 453.

(where the ore is strong and the vein has been followed a long distance in the mine) the western 5,500 ft. opened up has a general strike of N. 75 deg. W., and this stretch includes all the ore shoots; the strike of the eastern 2,000 ft., along which stretch no ore was found, is N. 85 deg. E.

Vertical Distribution of Ore Shoots.—As to the vertical limitations of the ore, no such explanation is possible. The vein has the same dip below the orebody as in it. But a very definite and striking vertically limited factor was detected by our examination. The flat top of the ore (which is about at the same level, speaking generally, throughout the productive portion) coincides with the bottom of the lowest andesite flow. The vein fissure goes up through the andesite, as, indeed, does the quartz and other vein filling, but the gold is lacking. Similarly, below the ore shoots, the vein fissure goes down strong; and the vein filling is also strong beneath the ore shoots; but gold is lacking. In other words, the vertical limitations of the ore shoot and its shape, depend upon a copious deposition of gold in the vein, only in the areas designated in the projection (Fig. 18), which areas correspond with the areas stoped.

The concentration of gold was greatly in excess of that usually found in those gold-quartz veins which show ore shoots more persistent in depth, as the Mother Lode veins in California or the mines of Porcupine (Canada). In ores of this type the ore runs, say, $5 to $8 per ton, and the ore shoots (namely the concentrations of gold in the quartz) have a vertical extent of several thousands of feet. The Camp Bird ore averaged $27.91 in gold for the six years previous to my examination, and the vertical extent was only 600 to 700 ft.! Evidently, an unusual concentration has taken place in the case of the Camp Bird. If the ore were reduced to the average grade—say $5—of the Porcupine or Mother Lode ores, the ore shoot would have had to be 3,500 to 4,000 ft. deep to contain the same amount of gold. The problem, I desire to repeat, is not in any of these cases one of the distribution of quartz or other vein filling, but of the distribution of gold within or near the quartz vein, for that is what makes the ore.

At the Camp Bird, therefore, we have a vein which came up through some 2,600 ft. of andesite breccia till it struck an andesite flow 50 ft. thick; in some way this andesite flow pulled the trigger and let off a delicately adjusted tension, and the gold was thrown down in the vein, just under the andesite sheet. One would not have believed it if one had not seen the clear evidence. In some way the gold was unable to pass through the vein fissure in andesite; in some way the obstruction was great enough to cause precipitation below. What caused the definite horizontal zoning of ore deposition? Was it chemical or physical?

Cause of Distribution of Ore.—The chemical explanation, to which we habitually turn, is in this case definitely excluded. The blocks in the andesite breccia, from top to bottom, are of the same andesite; and the andesite of the flows is also of the same kind. That the flows came from the same volcanoes as the breccia is indicated by the interbedding of the breccia and the flows above the orebodies. The whole volcanic period of andesite eruption, from the bottom of the breccia to the bottom of the rhyolite, was a simple and short-lived one; the great thickness does not denote great time, but great intensity. Violent explosive eruptions of andesite breccia were followed, when the violence calmed down, by a flow; then a shorter explosive paroxysm; then more flows, and the andesite period was at an end. The rhyolite came later. But as regards this 50 ft. lowest andesite flow which has been the main factor in producing the Camp Bird ore shoots, the breccia above it is identical with that below; and it differs from these breccias only in being a solid flow and not a breccia.

Its influence upon the localization of the ore—upon the deposition of gold—must therefore have been physical. And this is a conclusion which we would not expect, because andesite is as a rule a favorable wall rock for ore veins. It breaks cleanly, forming well-marked and straight fissures; it is sufficiently penetrable so that it can be replaced to a certain extent by ore solutions. Many of our best veins, of this same Tertiary shallow-formed type, are in andesite. Indeed, it is perhaps the most popular host-rock of all, in the Cordilleran region of North America. Why,

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therefore, has it inhibited the ascension of the gold in this case?

The breccia in which (just below the andesite flow) the gold was thus so suddenly and concentratedly dumped, does not seem, according to our habitual impression, so favorable a wall rock as the andesite. It is not so firm, in consequence of its origin; although, to be sure, we perceive that it was firm enough so that the vein fissures traversed it for great distances without scattering or weakening.

Discarding our expectations, therefore, we must get down on our hands and knees and inspect the present case. What physical difference is there between the andesite flow above and the andesite breccia beneath? Only that of *porosity,* apparently; the matrix of the breccia, being finely fragmental, is more porous than the solid lava. And this greater porosity must (by the process of elimination) be the reason for this important ore localization—for the pulling of the tension trigger which produced gold deposition. Let us note, however, that the porosity of the breccia is the same for the whole 2,600 ft. of breccia; and that the ore horizon of 600 to 700 ft. directly below the andesite flow has no especial advantage in this respect. The flat top of the ore, indeed, shows that *the andesite flow has acted as a dam to the gold.* But this is not the kind of a dam that we ordinarily find in ore deposition—where an impervious bed—such as a shale bed—blocks the fissure, so that the ore solutions or ore magma cannot pass up, but must spread out sheet-like below the impervious layer. The fissure went up cleanly through the andesite; and the vein solutions went up. The vein is as wide, or nearly as wide, in the andesite as below. The gold-bearing vein does not replace the walls to any noticeable extent; it is confined between the walls—a true fissure vein—whether these walls are breccia or andesite.

The longest and best available cross-section of the vein is through one of the two small ore shoots in the mine where the ore persists above the 50 ft. andesite flow—this upper ore shoot being, as seen on the plane section of the vein (Fig. 18) only some 150 ft. long, above the andesite flow, while immediately beneath

the flow the ore shoot is over 1,200 ft. long. The plane section shows that this narrow shoot of ore runs up, through the breccia which overlies the 50 ft. andesite flow, nearly to the thicker andesite flow 300 ft. above, but stops when it gets there; and that is the absolute top of the pay ore in the mine. A little ore occurred in the very bottom of this andesite flow.

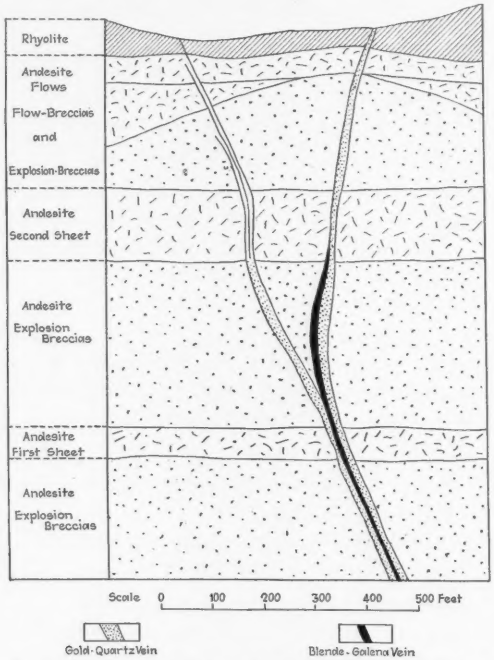

FIG. 20. Exceptional cross-section of Camp Bird vein, through line *A–B* of Fig. 18. Section line also shown in Fig. 17.

The cross-section (Fig. 20) at this place shows that these andesite flows have actually influenced the dip of the vein also. They have tended to deflect it from its normal 70 deg. dip toward the vertical. As shown, the vein branches after penetrating upward through the 50 ft. andesite flow, and the thicker branch goes up

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about vertical. On penetrating the second andesite flow, it leans further back than the vertical, so that its steep dip is slightly reversed. The narrower branch keeps its normal dip till it strikes the upper andesite flow, when it turns vertical and becomes much narrower, "petering out" into stringers; then, regaining its normal dip, keeps on, an insignificant vein, to the surface, where, like the other branch, it outcrops in the rhyolite. It will be noted that the main vein, where it crosses the upper andesite, is narrower than the underlying portion: it is also practically barren of gold here, although the quartz which carries the gold below goes on up—but without the gold. Where the vein enters the bottom of the rhyolite, it is still further constricted, and its outcrop is insignificant.

From this phenomenon of change of dip of the vein on penetrating the andesite flows, it is evident that these offered a slightly greater resistance to the breaking force than did the breccia. The change of dip indicates that. The temporary vertical direction is that assumed because following the direction of least strength of the flows—at right angles to their horizontal extent. Nevertheless, that does not offer any explanation as to why the quartz ascended through the fissures in the andesite, but the gold refused to follow. A vertical vein would invite the upward passage of ore solutions as urgently, surely, as a 65 deg. dipping vein. We must fall back again on the only remaining possible factor of relative porosity. Indeed, this occurrence seems to form a splendid and conclusive example of a principle which I have deduced for Porcupine [8] and again for Cobalt,[9] both in Canada. I quote from my Porcupine paper:

> Another thing which deserves to be carefully considered is the effect of wall rocks at Porcupine on ore deposition. The vein fissures and the veins are subsequent to the porphyry intrusion, into which they pass; but good ore rarely occurs in the porphyry, except near the contact with some other rock. Yet good ore in quantity may in places occur just under the porphyry, where an ore-bearing fissure intersects the contact, as in the Dome, whence Mr. Wright infers there a previous decomposition

[8] *E. & M. J.–P.*, vol. 116, No. 15, p. 637, Oct. 13, 1923.

[9] *E. & M. J.–P.*, vol. 116, No. 17, Oct. 27, 1923, p. 712.

and softening of the porphyry, so that it obstructed and dammed the ore magma solutions. And indeed much the same relations may be observed elsewhere. But where a strong quartz vein does lie in the porphyry, as I observed it on the surface at the McIntyre, why is it low grade or nearly barren? Here I observed little or no replacement of the porphyry walls to ore. Yet the intruding ore magma was of the same age and stage, and therefore was of the same composition, as that which formed rich ores in the nearby Keewatin "greenstone" schists—ores carrying good gold values both in the quartz and in the dark replaced walls.

The inference I draw is that the magmatic gaseous-tension pressure of these metalliferous submagmas was sufficient to allow it to penetrate and replace the Keewatin wall rock, and insufficient to allow it to penetrate the porphyry wall rocks, which in turn argues a relative imperviousness of the porphyry, and therefore, probably, as Mr. Wright inferred, a previous greater softening by decomposition. And this consideration, if it be true, as it appears to be, shows that relative pressures play a great part in the locus of actual deposition of ores, (for apparently the temperatures were the same, whatever the wall rock). Considering this further, we note that in the Hollinger and McIntyre, where the ore had as its choice of wall rock only the Keewatin "greenstones" and the porphyry (both schistose), it formed in the greenstones ores perhaps more important quantitatively and qualitatively than were formed elsewhere in the region; but in the Dome, where the choice lay not only between the Keewatin and the porphyry, but included the sedimentary rocks —especially conglomerates—of the Temiskaming as well, the selection fell overwhelmingly on the Temiskaming, out of which 80 or 90 per cent. of the ore has been taken, with the remainder from the Keewatin. We must infer, looking back to the Hollinger-McIntyre, that had there been no Temiskaming sedimentary rocks at the Dome, there would have been far more ores deposited there in the Keewatin than has actually been the case. The conglomerate is evidently a pervious rock—probably more pervious than the Keewatin, just as the Keewatin is probably more pervious, as above stated, than the porphyry, so that the critical conditions of wall-rock replacement in the district, and therefore of the formation of the wall-rock ore which forms the bulk of all the ore, was relative penetrability—the relative resistance offered to the gaseous-tension pressure of the residual ore magma. But, furthermore, as we have seen in the case of the barren quartz veindikes found in the porphyry, the lack of the deposition of ore by replacement of the wall rocks (where a relatively resistant or impervious rock has been penetrated by the ore-magma veindike) seems to be accompanied by a comparative lack of gold and pyrite deposition with the quartz itself, whether contemporaneously or in

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characteristic slightly later cracks and fissures. A connection between the two (white and black) classes of ore is thereby established, as if the relief of pressure in the ore magma which was attained by expansion into the wall rock not only allowed the crystallization of the metallic minerals in the penetrated rock, but, extending back into the uncrystallized ore magma between the walls of the veindikes, procured a similar deposition there also. Certainly, at any rate, the ore magma which formed these barren quartz veindikes in porphyry originally contained all of the ingredients of the productive quartz veindikes in other rocks, into which productive veindikes the barren veindikes pass; and the nature of the wall rock has determined the relative local concentration of metallic minerals.

And I quote from my Cobalt paper:

The great influence of wall rocks in determining the locus of precipitation of the net final fraction of the ore magma is as striking at Cobalt as at Porcupine, or even more so. At Porcupine, it will be recalled, a gold-quartz veindike (for example, in the McIntyre mine) which runs from the (basic) Keewatin schists into the (siliceous) porphyry, is apt to lose most of its gold values, though the veindike itself may proceed bravely on. And at Cobalt 80 per cent. of the ore has come from the conglomerates and other sediments of the Cobalt series, into which series the diabase has intruded. Most of these exposed sediments, at Cobalt, underlie the diabase sill, which has been partly stripped off by erosion; and veins pass down from the conglomerates into underlying Keewatin (basic) schists, representing ancient lava flows essentially like those of corresponding age of Porcupine. Many of the veins lose much or practically all of their silver values when traced (downward) from the conglomerates into the Keewatin, while the vein itself (of smaltite, niccolite, calcite, etc.) sometimes proceeds on in full width. The controlling influence of the wall rock on the precipitation of the final (silver) fraction of the ore magma is clear; and the explanation of this striking phenomenon is as nice a problem as in Porcupine—or still more exacting.

Considering first, the chemical influence of wall rocks on silver deposition, I have pointed out [10] that the basic-derived ore magmas, being calcic, would be most influenced to precipitation by siliceous wall rocks, just as the siliceous-magma-derived ore magmas, being themselves siliceous, are best influenced to precipitation by basic wall rocks. This would appear to be upheld at Cobalt, where the conglomerate and other sediments of the Cobalt series, containing a large amount of granitic material,[11] should

[10] "The Ore Magmas," vol. II., p. 654.

[11] W. G. Miller, "Guide Book," Ont. Dept. Mines, 1923, p. 69.

precipitate from calcic solutions more readily than should either the Keewatin schists or the Keweenawan diabase, both basic rocks. Dr. Miller says:[12]

"Judging from the way in which silver is found in the minutest cracks in granite boulders of some of the conglomerate near the veins, this ore, at least, was precipitated no less readily in acidic rocks than in basic ones. With the exception of these boulders, there are few opportunities afforded of observing the relations of the ore to granite. But in the Temiskaming mine, a few hundred feet below the surface, narrow dikes of Lorraine granite intrude the Keewatin and are cut across by a vein. The surface of the granite is plated with native silver."

While this theory as I have set it forth above, seems adequate to explain the influence of wall rocks on silver deposition at Cobalt, even more fully than the same theory does at Porcupine,[13] I am still inclined to suspect, as at Porcupine, a physical reason also. At Porcupine I have found reason to suspect that relatively penetrable wall rocks induced not only replacement of walls by gold magma-solution, but a corresponding precipitation in the veindike itself, by relief of gaseous-tension pressure due to expansion into the wall rock; and that for this physical reason relatively impenetrable wall rocks were unfavorable, not only for replacement ore, but for the best values in the intrusive veindike also. And at the Dome mine I mentioned how where the choice lay between Keewatin and Temiskaming sediments (conglomerate), 80 to 90 per cent. of the ore was deposited in the sedimentary rocks. Now, here at Cobalt, where the choice is between Keewatin (and diabase), and the Cobalt series of sediments (resembling in a general way the Temiskaming), 80 per cent. of the ore, or more, again chooses the sediments. Since the two types of ore magmas, in my opinion, differed greatly chemically, one being siliceous and one calcic, the choice of the conglomerates over the Keewatin schists seems to me to indicate a physical reason, probably collaborating with the chemical reason which I have submitted above; and that physical property I should call penetrability. Accordingly, where the ore magma (at Cobalt) penetrated (upward) along fissures in the Keewatin, and entered the Cobalt conglomerates, the gaseous tension of the magma was able to overcome the resistance of the conglomerate wall rocks, and to penetrate them; and, by the consequent relief of pressure, silver was at once deposited not only in the wall rocks but to a greater extent in the veindike as well; and this process was doubtless accelerated by the favorable chemical composition of the wall rocks, as I have pointed out above, producing the unusually sharp governing influence of these wall rocks

[12] *Op. cit.*, p. 96.

[13] *Eng. and Min. Journ.-Press*, vol. 116, No. 15, p. 637–638.

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shown at Cobalt. The suggested pressure factor probably operated at a constant temperature, for the different formations, as it did at Porcupine; for while some of the veins (in both districts) are impoverished on passing *downward* into an unfavorable formation, others are correspondingly impoverished on passing *upward* into an unfavorable formation—such as those veins at Cobalt, which lie in the Keewatin below the diabase, but do not extend upward into the diabase.

The deduction of this principle, which I was thus enabled to make more definite from the Cobalt phenomena than for the Porcupine case, is finally pinned down to its ultimate limits by this Camp Bird occurrence; for while the walls at Porcupine and Cobalt differ chemically as well as physically, those at Camp Bird differ only physically. And the application of the principle is more astonishingly shown at Camp Bird than in these instances, for at Camp Bird the amount of ore in the wall rock—if, indeed there is any—is not noteworthy. In Porcupine as much or more gold has penetrated the wall rock from the quartz veindikes, which occupy the fissures, than was deposited in the veindikes themselves; in the Cobalt region most of the silver was precipitated in the calcite veindikes, but a large amount was also expelled into the wall rock and made the low-grade "milling" ores of the district. The hypothesis may therefore be tentatively stated:

In ore-magma veindikes, metals (especially gold and silver) are in a more volatile condition than the quartz or calcite; they are therefore highly migrative, and tend to concentrate after veindike intrusion but before freezing, into certain portions of the ore magmas. Given about the critical temperature necessary for their deposition from solution, their solidification, and that of the rest of the ore magma, depends on the abstraction from the magma of the gaseous constituents which constitute an essential ingredient of the ore magma. These ingredients are abstracted by escaping from the ore magma, whether upward along the fissure, or laterally into the wall rocks; and therefore the more penetrable wall rock is the most favorable for the precipitation of gold and silver *within the veindike*. Part of the gold and silver,

being, as above stated, more volatile and penetrant than the gangue, may also penetrate the wall rock; or it may be only the non-metallic gaseous constituents (including aqueous vapor) that thus escape, and so accomplish precipitation of these metals within the veindike.

Where a veindike passes upward from a more penetrable to a less penetrable wall rock, the gases of the magma are suddenly confined by the less penetrable rock, which produces an excess of gaseous pressure in the ore magma, which excess pressure is transmitted to (backs up to) the ore magma standing immediately below the less penetrable rock; and the nearest relief of that pressure is by the escape of gases into the more penetrable rock immediately below the less penetrable rock. This is the case at the Camp Bird. Where the veindike passes upward again from a relatively impenetrable rock to a more penetrable rock, evidently ore deposition will take place again if there is any gold or silver left in the ore magma; and this occurs both at Cobalt, as stated in the above quotations, and (to a very minor degree only) in the Camp Bird vein.

Another observation made for the Cobalt problem would seem also to have an important application to the Camp Bird vein:

> The explanation for the high migrativeness and concentration of native silver above given, involves, of course, an upward as well as outward pressure in the veindikes: and accordingly, the tops of veindikes (for some of the veindikes have been found to terminate upward in the mines, constituting so-called "blind" veins) are said to be ordinarily relatively high in silver.

The Camp Bird occurrence shows that in the standing fluid veindike, which had a vertical extent of several thousand feet, the gold tended to migrate upward to an unusual extent, and to travel thus thousands of feet; for below the horizon of ore shoots there are only low gold contents. Comparing this high degree of vertical concentration of gold in the Camp Bird gold-quartz vein with the less potent concentration in the deep-seated gold-quartz veins, such as the Mother Lode region in California and the Porcupine district in Canada, one is led to consider the possible

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reason. In the deep-seated veindikes the gravity pressure is more uniform; in the superficial veindikes the proximity of the surface to the top of the vein offers a great gravity pressure differential between the portion near the surface and that some thousands of feet down. The more volatile ore-magma constituents—among which are the metals gold and silver—therefore press upward actively as soon as the veindike is injected; and accomplish a far greater vertical differentiation between gangue and metal, in the interval between injection and freezing, than is possible for the deep-seated ores.[14] Thus, the superficial bonanzas were formed, characteristic especially of Tertiary veins and veindikes; and they are correspondingly limited in vertical extent. If the $30 Camp Bird ore had not been thus concentrated near the top of the vein, it would, as I observed above, have sufficed for a vertical extent of 3,500 to 4,000 ft. of $5 ore like the ore of the deep-seated veins in the districts cited for comparison.

The ore in these superficial veins and veindikes never reaches the surface; therefore it cannot reach the surface, as I have argued:[16] Within 500 to 1,000 ft. of the surface, the relief of gravity pressure is so great that the ore magma disintegrates in any event, whatever the wall rocks; the gaseous ingredients escape upward as well as outward; and the metals (their carriers

[14] On the other hand, the freezing process in the gold-quartz veins in depth is much slower than for the superficial gold-quartz veins, as is universally acknowledged to be the case for all plutonic magmas as compared with the volcanic ones. In the case of igneous rocks, this brings about a coarser and more complete crystallization in depth, and even a partial segregation of constituents, producing more or less advanced differentiation; while the volcanic magma freezes with dense texture and without differentiation. In the case of the deep gold-quartz vein, this slow cooling permits a fractional crystallization whereby the gold (and other sparse metals) is crystallized pretty distinctly later than the bulk of the quartz, producing the streaks of gold and sulphides which fill rifts and little fissures in the quartz and penetrate the wall rocks, and which are prone to be wrongly interpreted as indicating a distinctly later period of ore injection. In the superficial gold-quartz veins this phenomenon is much less common; though a transitional condition appears in some veindikes, especially the thicker ones. An example of the last-named type is the Prospectus vein, Aurora, Nevada.[15]

[15] See "The Ore Magmas," vol. II., p. 692, Fig. 116.

[16] "The Ore Magmas," vol. II., pp. 549–557.

having thus deserted them) are precipitated in abundance. Now, in the case of the Camp Bird vein, the top of the ore was deposited some little distance below the surface. The rhyolite, into which the barren vein passes upward, is the uppermost formation, and underlies a gently eroded peneplain. This peneplain, since all volcanic activity (including the dike and ore injections), has been greatly uplifted (but without folding or faulting), so that erosion has been swift and the dissection stupendous. The maximum thickness of the Potosi rhyolite is given by the U. S. Geological Survey Publications at 1,250 ft.; and the top of the principal ore horizon of the Camp Bird vein is 700 ft. or more beneath the bottom of the rhyolite, above which the little tongue of ore described above goes some 300 ft. It therefore appears that the top of the ore may have been 2,000 feet or more below the surface; and that had there been no critical changes of formation, like those described as having pulled the tension trigger, the gold would have ascended further up—as the quartz did—before being precipitated.

I have discussed these principles before discussing the character of the gold veins, and have made the bald statement that they were veindikes.[17] The inclusion in the veins of numerous angular unsupported fragments of the wall rock, affords, as is so often the case, evidence that the quartz ore magma was substantial enough to hold these fragments in suspension till it froze. An unusual and striking bit of evidence has been recorded by Purington:[18]

> A somewhat remarkable occurrence may be mentioned at this point which was brought to the writer's attention by Mr. Laurence Cronin, the mine superintendent. It was a jagged and angular inclusion in the vein (in the stope over No. 4 chute, in No. 3 level), about 12 in. long and 6 in. broad, and consisting of a mixture of very finely crystalline and amorphous silica, of laminated structure and slightly pinkish tinge. Closely examined, it was seen to contain very small druses lined with quartz crystals. Hydrochloric acid causes effervescence in all parts of the

[17] Even though they occupied openings principally made for them by lateral differential movement along the fissure (p. 123).

[18] *Trans. A. I. M. E.*, vol. XXXIII., p. 514.

specimens taken. Two other similar but smaller inclusions were observed in the center of the vein (here 6 ft. wide), near the one described. In the largest mass, the laminations were nearly at right angles to the dip of the vein.

These inclusions had, in fact, all the appearance of fragments of silicified sedimentary rock; and their position at this horizon seems almost inexplicable. An analogous occurrence was, however, found, several months ago, by Mr. Arthur Collins, manager of the Smuggler-Union property, in the upper workings of that mine, and consequently at a horizon fully as high as in this case. That was even more remarkable; since the inclusions, though smaller, were, to all appearance, metamorphosed limestone, containing what appeared to be fossil crinoid stems. Mr. Collins kindly allowed me to examine the specimens shortly after their discovery.

The writer is unwilling to adopt, without further evidence, the opinion that these fragments have been brought up from below. Yet from what nearer source they could have been derived it is impossible to see.

These inclusions were in the ore of the Camp Bird vein. The limestone fragments must have been brought up from the Paleozoic limestones, a vertical distance of 3,000 ft. or more! What was inexplicable on the theory of slow ore deposition from waters circulating along open fissures becomes easily understandable on the theory of the injection of relatively dense ore magmas.

OTHER FEATURES OF THE VEIN.

It would be more satisfactory in some ways to the writer if he could end the analysis of the Camp Bird ore occurrence at this stage, and if there were no further confusing complications. Unfortunately, for this purpose, there is more to the history of the vein. The Porcupine veins and those of Cobalt are one-period veins. The slightly different stage of deposition of the constituent minerals, and especially the slight but all-important later (though overlapping) stage of crystallization of the metals as compared with that of the gangue, are to be referred to processes of differentiation within the body of veindikes injected at a single period, and these processes of differentiation have depended upon relative migrativeness of the different constituents, the metals as a whole being more migrative than the gangue fraction,

on account of greater gaseous tension, and hence being concentrated by upward and outward flow. This is the same principle that I have appealed to in the above discussion of the Camp Bird vein, in which discussion I have treated the vein as a single gold-quartz vein. This is true for the Camp Bird gold ore—for the Camp Bird stopes, and in fact for the whole vital and significant history of the mine, as sketched above. But the morphology of the vein shows that the vein, seen as a physical entity in a close-up view, is not a single-period vein: it is, indeed, an excellent example of a compound vein (Fig. 20). The gold-quartz vein which I have discussed above was a definite injection, and an independent vein; but before this injection, and again after it, the same fissure was utilized for injections of vein material of distinctly different types.

Galena-Blende-Pyrite Stage.—I have noted above that most of the veins in the immediate vicinity of the Camp Bird have a N. 45 deg. W. trend, more or less, while the Camp Bird has a general trend, roughly speaking, of N. 70 deg. W., more or less. (N. 77 deg. W. for 7,200 ft. measured on the second level.) Practically all of the NW. (N. 45 deg. W.) veins (Fig. 17) near here are different from the Camp Bird; they are galena-blende-pyrite veins, carrying a little silver but practically no gold: the gold-quartz of the Camp Bird vein is sparse or (usually) entirely lacking. Some of these galena-blende veins are strong, and have been prospected and mined in happier days, when silver commanded a higher price.

Study of the Camp Bird fissure shows that it existed before the galena-blende-pyrite vein period; and that it was first occupied by a vein of this type. Later the fissure was reopened, and the Camp Bird gold-quartz was injected. There were later episodes also. A barren often vuggy quartz partially occupied fissures in the vein caused by a reopening later than the arrival of the gold-quartz. And a still later movement produced fissures which remained unoccupied, and are marked by gouge or breccia bands and open fissures (Figs. 21, 22, and 23).

In the horizontal direction, the earlier vein—the galena-blende-

pyrite-rhodonite vein—was localized in a shoot by the same process of horizontal differential movement which has been described

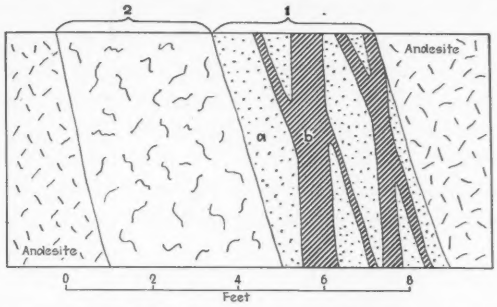

FIG. 21. Sketch of Camp Bird compound vein, Chicago level, showing gold-quartz vein on footwall and sulphide-rhodonite vein on hanging wall. 1, earlier sulphide rhodonite vein (*a*, rhodonite; *b*, sulphide). 2, gold-quartz vein.

above for the Camp Bird gold-quartz vein. The Discovery shoot—the largest and westernmost—is the principal shoot of

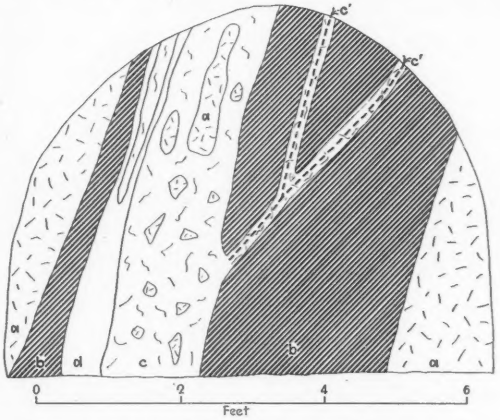

FIG. 22. Cross-section of Camp Bird compound vein, at a point on the third level; *a*, andesite; *b*, sulphide (blende-galena) vein; *c*, gold-quartz vein; *c'*, median band of contemporary sulphides in center of small *c* veins; *d*, barren quartz vein.

the galena-blende vein as well as one of the two principal shoots of the gold-quartz vein. But in the second of the two principal shoots of the gold-quartz—the Bluebird shoot—the galena-blende vein is insignificant and practically absent, and this is the case also in the two other principal lesser shoots further east—the Gertrude and the Hancock shoot. But in the case of the Hancock shoot of gold-quartz ore on the Camp Bird vein, a cross-cut into the footwall on a level near the top of the ore-horizon has developed a vein—the Hancock vein—of the early galena-blende-rhodonite type above, with no gold quartz, and

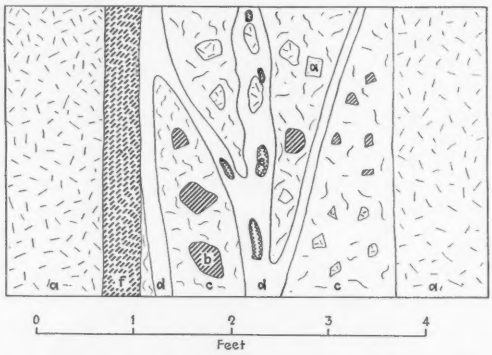

FIG. 23. Sketch of Camp Bird compound vein, Chicago level. Roof of drift (horizontal plan). Shows gold-quartz vein with included fragments of sulphide vein and of andesite. Later than the gold-quartz vein is barren quartz with central vugs, and still later a barren gouge band. *a*, andesite; *b*, sulphide vein fragments, enclosed in: *c*, gold-quartz vein which is cut by: *d*, barren quartz, containing: *e*, central vugs. Last is: *f*, gouge band.

diverging only slightly to the northwest from the general strike of the Camp Bird vein at this point. It was of no economic value, like most of these galena veins. Nevertheless, the galena-blende ore extends thinly throughout the Camp Bird vein, showing that these ore solutions came up where feasible along the whole fissure. The Discovery shoot trends more to the north of west

than any of the other shoots of the mine. Therefore a slight differential movement along the Camp Bird fissure, as above (p. 123) described, the south side moving relatively to the west, would open up the Discovery stretch of vein more than the other northwesterly stretches. Indeed these other northwesterly stretches including the Bluebird, were not opened up at all at the galena-blende stage—the galena-blende vein as such does not exist in them, except in traces. I have estimated that a horizontal shifting of 5–10 feet along the Camp Bird fissure took place to form the opening which concentrated the galena-blende vein in the Discovery shoot.

The details of the stages of the compound vein in the Discovery shoot are best shown in Figs. 21, 22, and 23.

Barren Quartz Stage.—The barren quartz, which succeeded, as a definitely later injection, the Camp Bird gold-quartz, filled fissures apparently created by a slight renewal of the horizontal differential movement. The last movement, later than all vein material, also was due to a horizontal differential movement along the vein fissure.

Horizontal Movements.—Thus there were three distinct renewals of the horizontal differential movement, subsequent to the original formation of the fissure, and each stage of movement, except the last, was followed by penetration of vein-material into the fissure. It is evident that each movement operated to pull out along the line of strike, the vein material already deposited: the result is that the vein broke and was separated along the strike: and the subsequent vein filling reigned nearly supreme in these intervals between the disjointed earlier vein stretches. And the final movement resulted, similarly, in the stretches of barren gouge or breccia along the vein, separating the stretches of the compound vein formed by the compounded injections of the three vein periods—galena, gold-quartz, and barren quartz. The pulling apart of the shredded fragments of the vein amounts locally to as much as 60 ft. The last horizontal movement was apparently as judged from the detailed mapping of the levels (as the Zero, the Chicago, and the Fifth levels) to the west on the north

side, a reversal of the previous movements. In the case of the last movement abundant horizontal striae show that the direction of movement was indeed horizontal; I have estimated from a study of the detailed mine maps that the sum of the two movements which opened the fissures for the sulphide vein and the later gold-quartz vein was not over 15–20 ft., as shown by the size of the openings in the Discovery shoot.

I have found no more definite measure of motion. Surface mapping did not show offsetting of the northwest veins where they cut the Camp Bird fissure as they often do. The best conclusion we can come to is that the rocks on the two sides of the fissure, after having been separated slightly horizontally by a repeated differential strain, largely slipped back into approximately their original relative position, by the reversed direction of the last movement.

At each of the stages of vein opening there is evidence that the openness of the fissure at different places varied greatly. In the more open parts fissures doubtless originated; while the closed parts were relatively tight, and allowed very little circulation.

The gold-quartz vein is characteristically very full of angular intrusions of the country rock. Certain vein exposures show how an ore magma, which in a region of relative openness or comparatively slight pressure injects itself in enough body to be called a veindike, gradually loses its penetrant power where the wall pressure is greater, the breccia-vein changing into a series of veinlets crisscrossing the rock of the vein zone, till they gradually give way to the sheeted but impenetrable rock of the fissure zone.

The common, perhaps predominant, horizontal movement along vein fissures in many mineral districts (as shown by striae) has yet to be clearly explained; as has, indeed, the tendency of veins to an east-west strike. As I have stressed repeatedly, igneous intrusion, deformation (folding and faulting), and ore deposition are closely allied phenomena, which generally go hand in hand. In the Camp Bird case there has been practically no folding and faulting; the beds and flows remain horizontal. Deformation in the marked sense therefore is wanting, the case in this respect re-

maining one of the lead-zinc deposits of the Upper Mississippi region.[19] Igneous activity of course is conspicuously present, the basic andesite dikes being very close to the veins in point of age, and barely preceding them. The observed repeated slipping along the Camp Bird vein fissure was contemporaneous with the broad domical uplift which elevated the whole region without much disturbing it, and which brought the rapid erosion which produced the wild San Juan scenery. Such an uplift would of course involve a stretching tension in a horizontal direction, tending to stretch the horizontal strata and the horizontal volcanic layers. Under such a horizontal stress, what other slight differential movement took place along fissures would tend to be horizontal—provided the uplift is uniform and not differential. The same explanation may be applied to the vein fissures of the Upper Mississippi lead and zinc region. It remains to be seen how widely it can be applied. In this general San Juan region laccoliths of diorite porphyry and granite porphyry were intruded after the outpouring of the Potosi rhyolite, but before the injection of the basic dikes and the mineral veindikes;[20] and such intrusion may well have gone on in depth under the Camp Bird area also.

Distribution of Galena Blende Ore and Barren Quartz.—The galena-blende-rhodonite ore deposition in the Discovery shoot and elsewhere had a greater vertical extent than did the gold-quartz vein which followed it, although the former has never been of any important economic value. The total Camp Bird ore as broken down, had the following percentage of values: Au, 96 per cent.; Ag, 3 per cent.; Pb, 1 per cent.; Cu, .02 per cent. The gold-quartz, of course, was preferentially mined, although with some admixture of the galena vein, which is reflected in the above analysis.

In the galena-blende vein the galena is coarse, and the blende of the light "rosin" variety. Much of the ore ran only 8 to 10 oz. of silver with as much as 20 per cent. of lead—so that it was a

[19] J. E. Spurr, *E. & M. J.-P.*, vol. 117, No. 6, Feb. 9, 1924, p. 246.

[20] *U. S. Geol. Surv.*, Telluride Folio, No. 57, pp. 6–7.

low-grade argentiferous galena, with sometimes a sparse gangue, principally quartz. In many of the sections sketched these sulphides cut the rhodonite (which is dense and barren of values), showing the earlier formation of the rhodonite. In other localities, however, some rhodonite occurs intercrystallized with the sulphides. Even where the rhodonite is earlier than the sulphides, it accompanies them, not being present unless they are there; and the amount of earlier rhodonite is proportionate to that of the later sulphides. Rhodonite does not occur to any extent in the Bluebird and other shoots where the sulphides are not notably present. Much of the rhodonite appears to be probably an alteration of the andesite breccia wall rock[21] of the sulphide vein, which itself appears to be mainly a fissure filling or veindike of injection and not to have formed by replacement (Fig. 21). Some of the rhodonite, however, appears to have been a fissure filling. However, the crystallization of most of the sulphides was at least a slightly later stage than that of most of the rhodonite. Fig. 21 shows clearly these relations.

In the Discovery shoot, the sulphide-rhodonite vein is most developed at the top of the main stope as compared with those portions of the stope lower down. As depth is gained in the mine, the galena-blende-rhodonite ore is found to be more persistent than the distinctively gold-bearing portion of the gold-quartz vein. Indeed, within the downward extension of the Discovery shoot, the older (sulphide) vein was present in good width to the lowest level (Fifth), open at the time of my examination; but the length of the shoot diminishes rapidly—so that a projection of it shows the same tailing off below as in the case of the gold-quartz shoot. With depth, however, the character of the sulphides was observed to change. While galena predominated at the top of the ore shoot, the proportion of blende and pyrite increased with depth till on the Fourth and Fifth levels the vein is frequently blende and pyrite.

[21] This coincides with Ransome's suggestion for the possible origin of rhodonite in the Sunnyside mine; and his explanation for the rhodonite of the Saratoga mine, both in the general region. At the Saratoga the rhodonite has replaced limestone (Bull. 182, U. S. Geol. Surv., p. 132).

Rhodonite also decreases with depth and is scant on the lower levels. This indicates that most of the rhodonite was formed by penetration of the wall rock by manganese emanating from the sulphide solutions which filled the fissures at the earliest stages of vein filling, although little manganese crystallized with the sulphides.

While the maximum deposition of gold in the gold-quartz magma was immediately under the lower andesite sheet, the maximum deposition of sulphide and rhodonite from the sulphide magma was immediately below the upper andesite sheet. The thin lower flow, which stopped off most of the gold from the quartz magma, appears to have acted less efficiently in impeding the upward course of the sulphide magma. On entering the upper flow, however, the size of the sulphide vein was at once greatly diminished.

The change from predominant galena in the upper levels to predominant blende in the lower levels is a primary condition; and evidently conforms to the Zonal Theory,[22] the blende being deposited at a higher horizon than the galena. The change is very marked in this vertical space of 1,000 to 1,500 ft., which is unusually short; and indicates an unusual degree of cooling toward the surface at the time of ore deposition, a close spacing of the isogeotherms, probably due to the relatively shallow depth at which the sulphide magma was injected—a depth apparently not greatly different from that which existed at the time of the gold-quartz injection.

The gold-quartz vein, where it cuts and lies along side of the galena-blende-rhodonite vein, in the Discovery shoot, carries some sparse contemporaneous streaks of sulphides, mainly galena.[23]

[22] "The Ore Magmas," vol. I., p. 283.

[23] Ransome, F. L., (Bull. 182, U. S. Geol. Surv., pp. 89–90) has examined microscopically and described specimens of such gold ore, from the upper stopes of the Camp Bird mine. He describes it as fine-banded quartz, containing also fluorite, calcite, sericite, and chlorite, with small quantities of galena, blende, pyrite, chalcopyrite, and much free gold, with a trace of tellurium. He concludes (p. 93) that the ore was partly crystallized in open spaces, partly due to replace-

As this phenomenon is practically absent in the gold-quartz vein in the Bluebird and other shoots where the galena-blende-rhodonite vein is also practically absent, it is highly probable that the gold-quartz magma dissolved, after injection, a certain proportion of the constituents of the earlier vein. The earlier vein also appears to have acted as a precipitant for the gold and sparse native sulphides of the gold-quartz vein, for where the gold-quartz vein includes fragments of the sulphide vein, a rich dark ring of sulphides in many cases appears as the first deposition on the fragment, followed by lower-grade quartz. The average grade of the gold-quartz in the Discovery shoot was somewhat better than that in the other shoots, where these precipitants were lacking; in the East End of the Discovery shoot was the richest ore in the mine, some blocks averaging nearly $100 per ton.

The gold-quartz is of dense to medium texture, rather milky in appearance. The gold-quartz vein has produced a certain silicification of the wall rocks over a narrow margin. The physical distinction between the gold-quartz and the later barren quartz is clear. The earlier quartz is denser, and characteristically contains fragments of the wall rock, and also fragments of the earlier vein, angular but corroded or silicified by the quartz.[24] The later quartz is white and semi-transparent, is plainly a fissure filling, crystallizing from the walls inward, and where it adjoins the wall rock this wall-rock is not much corroded or silicified. Angular fragments of the sulphide vein, the earlier gold-quartz, and of the wall rock occur, but are uncommon; and in these cases the wall-rock fragments are little altered. The later quartz is *per se* typically barren of all values.

The movement which reopened the fissure for the gold-quartz magma to fill followed the entire course of the sulphide vein, but, in addition, sent out, both laterally and vertically, certain branches

ment of the andesite-breccia country rock. He finds a certain association between the free gold and the sulphide bands in the ore.

[24] Purington, C. W., (*Trans. A. I. M. E.*, vol. XXXIII., 1903, p. 512) observes: "Countless examples may be seen, in the mine workings, of perfectly angular fragments included in the vein matter."

not before opened up. The most important of these is the split above the first level, parallel to the strike of the earlier vein, but diverging from it in dip and representing the upward continuation of the general dip below the first level. But in addition to this divergence upward (which results in a one-period vein between the two andesite flows, consisting entirely of the gold-quartz period) the gold-quartz injection also followed the earlier sulphide vein, which after passing through the lower andesite flow had, above, a slightly reversed dip; and filled this fissure also, in equal or greater quantity than that in the one-period branch. These two veins outcrop on the surface (Fig. 17) where the gold-quartz one-period branch forms a loop, uniting, on the strike, with the main vein at both ends.

The barren (later) quartz vein which cuts the two earlier veins very frequently has central vugs lined with large crystals; and the vugs are often wide and continuous. The coarse crystals lining the vugs are generally quartz, sometimes fluorite, sometimes fluorite covered by later dense banded quartz, sometimes calcite. The vug linings reach 3 or 4 in. in thickness. They also carry in rare cases crystals of sulphides—galena, blende, and pyrite.

The barren quartz, which is older than these vug linings, often shows rough banding, with sparse metallic sulphides, and spotted free gold. In the lower levels, where the barren quartz lies alongside the earlier sulphide vein, and contains fragments of it, it appears probable that the solutions which deposited the quartz of the later barren period have dissolved a little of the contents of the metalliferous veins, just as in the stopes above it is evident that the gold-quartz magma also dissolved something from the earlier sulphide-rhodonite vein. The later barren quartz veins, unlike the ore-bearing veins which preceded them along the same fissure, are stronger in the lower workings of the mine than in the upper ones. The barren quartz was relatively small in amount above the third level; and widest, so far as visible, on the fourth and fifth, where gaping fissures 3 to 5 ft. wide were formed, not only along part of the stretches occupied by the ore above, but also over the intervening stretches, which contain no vein material of any kind above.

MODE OF FORMATION.

It is evident that this barren quartz was formed from a quite different type of solution from those solutions out of which consolidated the sulphide vein and the gold-quartz vein. These metalliferous veins are characteristically solid and dense; where they show a banded arrangement, it is a local detail and not typical; they never show vugs. In most places the evidence is that the vein filling froze at one time. Moreover, each of these represents typical ore magmas—the gold-quartz magma and the galena-blende-pyrite magma. The gold-quartz contains many angular supported fragments of the wall rocks. The surprising occurrence in the vein of fragments of the sedimentary rocks which belong thousands of feet below (p. 137) can be explained only by the assumption that the ore magmas were dense and semi-viscous, and that they were injected each at a single gush—that they were veindikes of a consistency comparable to certain pegmatite magmas. Along these same lines is evidence of the kind shown in Figs. 22 and 23, which are true sketches of local conditions and are not diagrams. In Fig. 22 the inclusions in the gold-quartz vein are of the andesite wall-rock, although the immediate walls were formed by the sulphide vein, showing that the included fragments were *brought in from outside the field of the section.* The same thing is shown in Fig. 23, where the gold-quartz vein carries included fragments of the earlier sulphide vein and also of the andesite; but there is no sulphide vein in place in this section. In this case also, the fragments of the sulphide vein must have been brought in from outside the plane of the section. Moreover, in Fig. 22 note the phenomena of the small branch vein, which carries a central streak of sulphides where it cuts the older sulphide vein. These sulphides in the quartz vein, as I have noted above, are characteristic only in the vicinity of the sulphide veins. In this case (Fig. 22) the explanation of the sketch seems to be that the fluid quartz magma which filled the branch vein dissolved some of the sulphides, which were crystallized, as the quartz magma froze from the walls outward, thus forming a

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central streak. The dense to moderate grain indicates a relatively rapid freezing. True banding is inconspicuous and local, the structure being typically massive. This is a condition true of mineral veins in general, and one that has been recognized and discussed with extraordinary perspicacity by F. L. Ransome [25] in 1901.

> In most of the important lodes of the Silverton quadrangle, no crustification can be detected. The fissures are filled by coarsely crystalline allotriomorphic aggregates of ore and gangue (massive structure) and there is no evidence to show that such a structure could result from successive deposition upon the walls of the fissure until the whole was finally filled. On the contrary, crystallization has proceeded simultaneously from many points within the solution. Quartz, galena, pyrite, sphalerite, chalcopyrite, and other minerals have formed practically contemporaneously about local centers of crystallization scattered irregularly throughout the solidifying mass. It is difficult to conceive all the details of a process which results in the formation from aqueous solutions of an irregular allotriomorphic aggregate of minerals differing so widely in specific gravity. But reasoning from analogy with similar structures met with in petrology and in the arts, it is fair to assume that this structure in veins is the result of the undisturbed crystallization of a nearly motionless saturated solution. In other words, it was the crystallization of a reservoir so large, in comparison with the current or currents which circulated through it, as to have been itself free from megascopic motion. The conditions which induced crystallization were present throughout the mass of material which filled the fissure, and solidification, instead of proceeding gradually from the walls inward, took place almost simultaneously, although not necessarily with rapidity, throughout the mass. Obviously this massive structure and crustification may be present in the same vein. In such cases deposition appears to have begun by crustification next the walls, passing at a later stage into the more general mode of crystallization indicated by what has been described as massive structure.

The conclusion arrived at, of "crystallization from a nearly motionless saturated solution" is precisely the hypothesis I am putting forward for the Camp Bird vein. The process, so accurately reasoned out, was as Dr. Ransome observed "difficult to conceive" as the work of "aqueous solutions" which elsewhere (p. 134) he assumes to have been modified "meteoric waters."

[25] Ransome, Bull. 182, U. S. Geol. Surv., p. 136.

But this phenomenon of uniform and contemporaneous consolidation of the whole fissure filling, like the flotation of sedimentary rock fragments described by Purington, is readily understood under my hypothesis that the solutions were not "meteoric waters" nor even hot spring waters, but dense ore magmas, containing probably a subordinate quantity of water and other volatile constituents, and constituting a highly differentiated phase of the igneous magmas.

The later barren quartz must have formed from more dilute solutions than the gold-quartz of the gold-quartz vein, and also

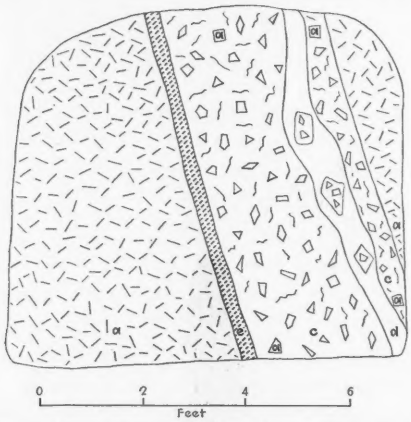

FIG. 24. Camp Bird Vein. Third Level. Showing barren quartz vein cutting and enclosing fragments of the gold-quartz vein. *a*, andesite wall rock; *c*, gold-quartz with many angular fragments of *a*; *d*, barren quartz, with included fragments of *c*; *e*, gouge.

from more dilute solutions than the blende-galena vein, and must have been deposited with greater comparative slowness. The ample fissures which these solutions occupy were characteristically only partially filled by the quartz crystals growing out from the walls. The vugs and empty fissures which remained offered shelter for the slow growth of quartz, calcite, and fluorite crystals from the walls, and the process was never completed.

I have been tempted to consider the possibility of the deposition of this barren quartz vein, and the vug linings, from ground water, but since the latest fissuring (marked by gouge and horizontal displacement) there has been no deposition whatever of vein material along the fissures: therefore the ground water is probably impotent. Indeed it is quite unlikely that the ground water would deposit a quartz vein, even if this water were active in forming veins—the materials it takes into solution are chiefly lime, iron, and manganese, of which the last two are lacking, and the first scant, in the barren quartz veins. Moreover, the strength of the barren quartz vein increases with depth. We must, therefore, I think, ascribe the formation as due to ascending solutions, probably hot, certainly siliceous, and as belonging to the close of the magmatic phenomena. The solutions may have been hot siliceous magmatic waters with no connection with ore magmas; or they may have been a highly aqueous and weak residual closing phase of the quartz magma which in its earliest injection carried gold and was not highly aqueous. I am inclined to the latter belief.

Certain phenomena, indeed, suggest that the barren quartz veins were not formed from continuously circulating solutions or waters, but represent fissure filling at a single gush. The circumstance that this quartz carries sparse sulphides and even low gold values where it lies adjacent to the earlier metalliferous veins which it cuts, and from which it has evidently dissolved these metals, indicates a standing rather than a circulating solution. The habit shown in Fig. 23 suggests the same conclusion. The restriction of the vugs, as sketched, to the central widest barren quartz fissure, suggests that the interconnecting fissures at this stage were filled with a single standing solution, the solid precipitates from which completely filled the narrower fissures, and the bulk of the main fissure; the volatile or permanently fluid constituents (including water) being residual and being driven to the middle of the central fissure, formed the solutions which filled the vugs, from which residual solutions, by slow crystallization, the vug-lining crystals were formed. From this con-

ception, the fluid which filled these fissures may be compared as to consistency with those especially fluid pegmatites which have characteristic residual vugs in the center, which vugs are lined with crystals of unusual perfection and variety; while the fluids from which the earlier sulphide and the gold-quartz vein crystallized must have been denser, and have contained a less proportion of volatile constituents; they must have had the consistency of the more ordinary pegmatites which do not contain vugs, and have a medium texture. Judging from occurrences like that shown in Fig. 24, moreover, some of the barren quartz, at least in the stage immediately preceding consolidation, was dense enough to support isolated and suspended blocks of the earlier quartz long enough for freezing to lock them in this suspended position.

NEW YORK, N. Y.

GEOLOGICAL NOTES ON A PART OF SOUTHERN TRINIDAD, B. W. I.[1]

CHARLES GORDON CARLSON.

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INTRODUCTION.

THE island of Trinidad, British West Indies, is situated near the northeast coast of South America at lat. 10.30 North and long. 61.20 West. It averages 47 miles in length by thirty-six miles in width and contains an area of about 1,750 square miles. The climate is tropical with an average rainfall of from 45 to 60 inches.

Trinidad is intimately related, structurally and stratigraphically, with South America, the Northern Range being a continuation of the Caribbean Andes. The areal geology of the island permits its division into five geologic provinces as indicated in the insert in Fig. 25. These geologic divisions comprise: (1) the Northern Range of metamorphic rocks, (2) the broad belt of alluvium-swamp deposits and outwash material—to the south of this range, (3) the much disturbed Cretaceous and lower Tertiary rocks of the Central range, (4) the Naparima marl belt of Mio-

[1] Published through the courtesy of the Whitehall Petroleum Corporation Ltd. (S. Pearson and Son Ltd.), London, England.

cene and upper Oligocene foraminiferal marls, clays, and interbedded sands and (5) the Southern Range, the core of which is made up of rocks similar to those in the Central range but which in the southern part of the island are largely covered by Miocene deposits.

The data contained in the present paper was obtained during 1921–1923 while the writer was a member of the Trinidad geologic staff of the Whitehall Petroleum Corporation Ltd., London. The writer is especially indebted to Mr. Robert Anderson, chief geologist of the above company and to Mr. G. A. Waring, formerly chief geologist of the Trinidad Petroleum Development Co. Ltd. (the subsidiary in Trinidad of the Whitehall Petroleum Corpn.), for generous coöperation in the field and helpful suggestions in revision of the manuscript. Messrs. H. G. Kugler, geologist of the Apex Oilfields of Trinidad, E. W. Beltz of the Whitehall staff, and M. Gerst, geologist for the United British Oilfields of Trinidad, have supplied information on special areas and offered many valuable suggestions. Paleontologic data has been largely furnished by Dr. G. D. Harris, who as consulting paleontologist for the Whitehall Petroleum Corpn., and in cooperation with the Trinidad geologic staff of that company, has determined the age of most of the sedimentary rocks of the Island.

The present geologic notes are concerned with only a part of southern Trinidad. Dr. Harris and Mr. Waring have under preparation a paper covering the general geology of the island.

Field Methods.—About one half of Trinidad is covered by dense virgin forest while the remainder is under cultivation chiefly in cocoa, sugar cane, and coconuts. The rocks are generally deeply weathered, this being as much as 15 to 20 feet in clay-marl areas. Good exposures, away from the coast, are found only along streams and in new road cuttings so that most geologic data has to be obtained by test pitting and augering. Test pits are dug from 6 to 20 feet in depth, depending on the character of the material. In the Naparima marl belt augering has proved valuable in differentiating between clay and marl areas.

Whether in forest or cultivated areas the distances one can see are usually so slight that the use of the plane table has not been found practicable. The common practice is to run prismatic compass lines along which, at certain intervals, are located test pits and auger holes. The folding is close enough to permit structural data being obtained direct by means of clinometer. The Batson sketching case has been found serviceable for reconnaissance mapping.

Data Previously Published.—A geological survey of Trinidad was made in 1856–1858 by Wall and Sawkins, the work being part of a geological survey of the West Indies. The results of the studies of these geologists were published in bulletin form in 1860.[2] Between 1860 until nearly to the time of his death in 1916 R. J. L. Guppy published several papers dealing with the geology of the island, most of which appeared in the *Quarterly Journal of the Geological Society* and the *Geological Magazine.* In 1904–1907 Mr. Cunningham-Craig, as government geologist, made a study of the natural resources of the island and his findings were published as Council Papers of the local government.

Several paleontologic articles, describing specific forms, have appeared in various technical journals. With the exception of a paper by Milner [3] there has been nothing published in recent years on the general geology of the island. The oil industry of Trinidad was reviewed in a paper by Macready in 1911.[4]

PHYSICAL FEATURES.

The Southern Range, with an average elevation of 125 feet, is the most outstanding topographic feature in southern Trinidad. The maximum elevation is reached along the extension of the Range to the east of the area considered in this paper and there several hills rise above 600 feet. The topography along most of

[2] G. P. Wall and J. G. Sawkins: "Report on the Geology of Trinidad, or Part I. of the West Indian Survey," London, 1860.

[3] H. Milner, "Trinidad: A Review of its Geology and Oil Resources," vol. 25, 1921, pp. 139 to 148 and 205 to 213.

[4] G. A. Macready, "Petroleum Industry of Trinidad," *Trans. Am.. Inst. of Min. and Met. Engrs.*, vol. 165, 1921, pp. 58–67.

the Range is rugged, the hills having steep and locally precipitous slopes. Characteristic of the topography are sharp crested ridges which trend about N. 70 to 80 degrees E., or parallel to the trend of the main Range. The location of these ridges has been determined by beds of hard calcareous sandstone which are interstratified with more easily eroded sands and sandy shale. Within the area of Oligocene and lower Tertiary beds there are resistant algal and orbitoidal limestones which form prominent isolated hills.

In the Cedros Peninsula and the oilfield district the topography, in major part, is rolling or gently undulating and in the area covered by Quaternary deposits the ridges are broad and flat topped. The average elevation from ridge top to stream valley is in the Cedros Peninsula about 75 feet. Many of the higher hills are formed of burnt carbonaceous shale or "porcellanite" and oil impregnated sands. In the oilfield district southwest of Pitch Lake outcropping pitch sands have developed a more rugged topography which is marked by irregular sharp crested ridges and short steep ravines. Where the porcellanite and oil sands reach the coast they form prominent Points such as Cedros Point, Point Fortin, and Point Galba.

The low lying or swampy districts, of which the largest is the Oropuche lagoon, form an outstanding physical feature and together occupy an area of about 35 square miles. These swampy areas are partially flooded during high tide and, in places, are entirely under water in the wet season.

STRATIGRAPHY.

General Statement.—The greater part of southern Trinidad is covered by sediments of Miocene age which unconformably overlie the lower Tertiary and older beds. The pre-Miocene rocks, in this part of the island, are exposed within the Southern Range where close folding and faulting has brought up the older beds and permitted erosion to remove the younger deposits. The area of outcrop of the lower Tertiary beds may represent, in part, areas which formed islands during Miocene deposition and which,

on being folded and faulted, have been more readily uncovered by erosion, owing to the lesser thickness of Miocene deposits overlying them.

Cretaceous.—Although beds of Cretaceous age are exposed in many parts of the Central Range no Cretaceous rocks, definitely in situ, are known in southern Trinidad. Small blocks of limestone of this age have been found at various places along the southern fault zone of the Southern Range, but usually imbedded in, or derived from, the mud flow breccias which have been formed by mud volcano action. One of these limestone blocks from Galpha Point contained a species of *Ditymotis* which has been identified as lower or middle Cretaceous. The presence of the Cretaceous blocks in the clay breccias argues for the presence at no great depth of the buried range of lower Eocene and older rocks.

Eocene.—Rocks of Eocene age are limited in southern Trinidad to a few small exposures in the Southern Range and to fragments brought up by mud volcanoes.

A glauconitic limestone which has been correlated by Dr. G. D. Harris with Midway Eocene forms Marac Hill (Fig. 25), a prominent isolated hill about 200 feet in elevation and covering an area of several acres. This is the only large outcrop of basal Eocene in southern Trinidad. Lithologically it is an argillaceous, sandy limestone which is green when fresh but weathers readily to a hematite red on alteration of the glauconite. The limestone contains as characteristic fossils, *Venericardia planicosta* and *Hercoglossa ulrichi.*

Paleontologic evidence from the Central Range indicates that the middle Eocene was a period of erosion. Upon submergence and the beginning of deposition of upper Eocene sediments a basal conglomerate was formed which contains large bowlders derived from the denuded rocks. This conglomerate in the Central Range marks a distinctive stratigraphic horizon which can be traced across the island. Large blocks of Cretaceous limestone containing well preserved ammonites and baculites are locally abundant in this conglomerate as are also bowlders of basal

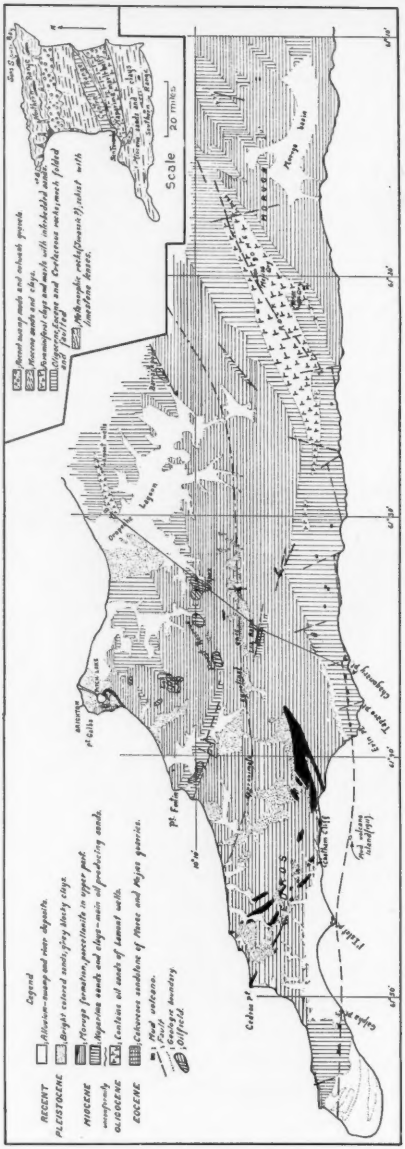

FIG. 25. Map of part of southern Trinidad. ———, 5 miles.

Eocene limestone resembling that from Marac Hill in the Southern Range.

The conglomerate has not been found in situ in the Southern Range but it seems probable that the chert pebbles and blocks of Eocene and Cretaceous rocks which are contained in the clay breccias associated with the mud volcanoes along this Range, have been derived from it and brought up by the mud volcano action.

The upper Eocene is represented in the Southern Range by rocks resembling beds of this age in the Central Range; mainly algal and orbitoidal limestones, hard marls and interbedded sandy shale and sandstone. These rocks are exposed only in a few places within the area of outcrop of the Oligocene beds (Fig. 25). Here the more resistant beds, such as the limestones, form some of the higher hills and there are outcrops of upper Eocene rocks along certain streams. The stratigraphic sequence of the lithologically different beds cannot be established with certainty owing to the complexity of the structure and the lack of sufficient exposures. The variation in the character of the beds indicates that they were laid down under rapidly changing conditions of deposition; partly within the littoral zone and to less extent in deeper water.

A comparison of the Cretaceous and lower Tertiary rocks of the Southern Range with the beds of this age in the central part of the island, suggests that if the cover of Miocene deposits were to be removed the Southern Range would stratigraphically and perhaps also structurally, resemble the present Central Range.

Some of the Eocene beds are petroliferous. The Marac limestone contains a light aromatic oil in fossil cavities and many of the upper Eocene sands are oil stained.

Oligocene.—Exposures of sediments of this age are limited in the part of the island here considered to small areas in the Southern Range and to a narrow zone along the Lamont-La Fortune anticline. There are also in places blocks of Oligocene rocks in the mud flow breccias.

The lower Oligocene beds consist largely of foraminiferal clay in which are interbedded algal and orbitoidal limestones. These

beds are overlain by a thickness of marl and marly clay, in the upper part of which are cherty sands that in places are petroliferous. The marl is largely made up of foraminifera of which Globigerina, Orbulina, and Nodosaria are most common. *Nodosaria abyssorum* is a characteristic form in the Oligocene clays, these clays being termed " bamboo clays " in local nomenclature. The marl has been found in the mud flow breccias along the entire extent of the southern fault zone and was also encountered in the wells drilled by the Trinidad Petroleum Development Co. Ltd. (Whitehall Petroleum Corpn. Ltd.) into the Oligocene beds of the Lamont-La Fortune anticline. The distribution of the marls and marly clays suggests that conditions of deposition during most of Oligocene time were uniform over a wide area. The sediments, being partly formed of the remains of organisms, indicate deposition in fairly deep water and in a zone which was not receiving much material from neighboring land areas.

The total thickness of the Oligocene deposits in the Southern Range is probably not over 600 feet, but is more than twice that in the Naparima marl belt.

Miocene.—Most of southern Trinidad is covered by littoral deposits of Miocene age which lie unconformably on the older beds. The unconformity involved no great period of erosion as the Miocene deposits, in major part, lie on rocks of Oligocene age. The hiatus was sufficient to allow the Oligocene beds to be slightly folded and faulted prior to their denudation and the deposition of the younger sediments. There is no evidence of any erosion interval during Miocene time.

The greatest thickness of the Miocene deposits is reached in the Cedros peninsula where it is over 7,000 feet. The deposits are interbedded sands, calcareous cemented sandstones, sandy shale, clays and lignites, which have been in large part laid down in the shallow water of the littoral zone under estuarine and deltaic conditions and in lagoons. The sandy beds show cross bedding on a big scale, ripple marks and mud cracks, the giant cross bedding being well seen in the coast sections of the Cedros peninsula. The sequence of beds varies from finely laminated shale to coarse massive sands.

The Miocene deposits are divided into the Moruga and Naparima formations. This division is an arbitrary one and, for convenience in mapping, was first made in the oilfield district where a thin distinctive clay member, the Naparima or Lot One clay, was used to separate the formations. The Naparima formation contains the important oil producing sands. The Moruga formation is the more arenaceous, containing thick coarse-grained massive sands while in the beds of the Naparima formation which have been deposited in deeper water, the sands are fine-grained and there is a greater thickness of clay or clay shale. In the upper Moruga beds are contained the " porcellanites " and most of the lignites and thick carbonaceous shales. The important lignitic beds are exposed on the north coast between Cedros Point and Point Fortin and on the south coast between Chatham Cliff and Erin Point.

While the source of the Miocene sediments is not definitely known it is believed to have chiefly been the mainland of South America. This source is suggested both by the lateral variation of the sediments and by their mineral composition. Magnetite and ilmenite are common minerals in the littoral Miocene deposits and these minerals are abundant in the pre-Cambrian rocks of Venezuela and the Guianas. In going northward from the south coast of Trinidad the littoral deposits are rapidly replaced by sediments deposited in deeper water, foraminiferal and marly clays, so that in the vicinity of the Oropuche lagoon the sandy beds of the Naparima formation are entirely absent (Fig. 26). The Moruga formation does not extend far north of the oilfield district. The approximate zone along which the Miocene sands " feather out " into clay is obtained by drawing a gentle curve from the Barrackpore Oilfield to a point about one mile north of the Apex Oilfield and then on to the coast about two miles east of Brighton.

Fossils in the Moruga formation are rare. Well preserved plant remains are found in the " porcellanites " and a few thin sandy beds have yielded molluscan forms. *Arca trinitaria,* found in the Miocene beds north of the Central Range, is also present in

the Moruga formation of the south coast. The clays of the Naparima formation contain the foraminifer, *cyclammina,* as a characteristic fossil.

Quaternary.—Deposits of Quaternary age unconformably overlie the older sediments. Their greatest areal distribution is in the Cedros peninsula especially in that part which structurally represents the trough of the southwestern syncline. These deposits are largely poorly consolidated yellow, red, and brown sands and grey blocky clays. Interbedded in the sands are lenses of hard iron cemented sandstones and conglomerates, the latter containing pebbles of white quartz, chert, and "porcellanite." The sands are poorly assorted and vary from coarse to fine-grained.

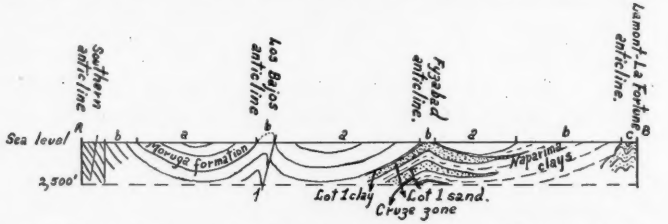

FIG. 26. Diagrammatic section from the southern anticline at Erin to the Lamont-La Fortune anticline. Length of section about 14 miles. Vertical scale twice horizontal. *A,* Moruga formation; *b,* Naparima sands and clays; *c,* Oligocene beds.

Fragments of leaves and other carbonaceous matter are present in some of the clays but not in abundance. Where the Quaternary deposits immediately overlie foraminiferal marls and clays as along the coast to the west of the Oropuche lagoon, they contain worn foraminifera derived from these older beds. These redeposited foraminifera are present in the younger sediments only within a few feet from the old erosion surface. Where the Quaternary beds overlie "porcellanite," a clay-conglomerate has been formed which is of a reddish color and contains large porcellanite fragments.

There is evidence in southern Trinidad for considerable uplift in recent times. The streams, especially in the Moruga basin,

have deeply cut channels and show evidence of recent rejuvenation. Along the southern coast raised beaches can be seen at many places, a prominent one being about eight feet above present high tide. Inland, some of the "porcellanite" hills have wave cut terraces which mark the presence of former shore lines, and at various places Quaternary iron cemented conglomerates, probably representing old drainage channels, are found along the ridge tops at various elevations.

The maximum thickness of the Quaternary deposits is in the Cedros peninsula and it is here not over 200 feet.

The character of the Quaternary sediments indicates that the climate during their deposition may have been less humid than that of today. This is suggested by: (1) the highly colored sands and conglomerates, the latter resembling the ferruginous conglomerates which form a large part of the Quaternary "Ilanos" deposits of Venezuela, (2) the scarcity of carbonaceous matter and (3) the presence of well preserved feldspars which in a humid climate are more readily altered to kaolin.

It is likely that the semi-arid conditions prevailed during the time interval between Upper Miocene and the deposition of the Quaternary sediments, since the carbonaceous shales were burnt to "porcellanite" prior to Quaternary time and this burning could hardly have taken place in a humid tropical climate such as Trinidad has today.

STRUCTURE.

That part of Trinidad dealt with in this paper contains three major structural units: (1) the southern anticline which is adjacent to the south coast and extends along the Southern Range, (2) the Point Fortin-Forest Reserve zone of uplift and (3) the broad shallow syncline lying between these two anticlinal areas. The "southern anticline" represents not a single fold but rather a broad zone within which the beds are steeply upturned or vertical and in places much broken by faulting. This anticlinal zone averages about four miles in width. Besides the major structural units mentioned there are subsidiary or minor folds upon

some of which are located the various oilfields and the famous Pitch Lake. The general trend of the tectonic lines in Trinidad is about N. 70 degrees E. and this holds for this part of the island except in the Cedros peninsula where the beds swing to the northwest. This change in strike is well shown by detailed mapping of the "porcellanites" (Fig. 25), and by the trend of the Point Fortin anticline.

The dominant structural feature in this part of the island, as elsewhere in southern Trinidad, is the closeness of the folding along the crests of the anticlines as contrasted with the broad shallow synclines. This structural feature is best illustrated by the anticlines of Point Fortin and Los Bajos, the folds in the oilfields to the north being more gentle. Along the crests of the two anticlines mentioned the beds are vertical or steeply dipping and much disturbed by minor faulting, and the Los Bajos structure represents a sharp squeezing up of the beds along a fault, almost in the trough of the southwestern syncline.

The strata of the Southern Range within the area of the Naparima formation have an average dip of 60 degrees and in places along the Range they are vertical over considerable distances. Within the area south of the Range which is covered by the massive sands and sandy shale of the Moruga formation there are several areas of uplift which expose the Naparima clay of the underlying formation. Within these uplifted areas there are minor isoclinal folds—usually less than one mile in length—which trend NE.–SW. and have their axial planes dipping to the north, indicating that the force which caused the folding acted from north to south. Along the crestal zone within the anticlinal areas the Naparima clay has been tightly squeezed into minor drag folds whereas the overlying massive Moruga beds have been much fractured and faulted.

From areal mapping and detailed study of the coast sections two sets of faults can be recognized within the complexly folded zone of the Southern Range; one set trending about N. 70 degrees E., or parallel to the strike of the beds and another set of cross faults trending from N. 10 to 20 degrees W. These strike

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faults form a prominent fault zone which is marked by intense fracturing and crumpling of the beds and, in places, by the presence of mud volcanoes.

With the exception of the Point Fortin and Los Bajos fields the structure in the oilfield district is simple as compared with that of the Southern Range. There is surface evidence of minor faulting along the crests of some of the anticlines but from subsurface data it is questionable whether these faults extend to any great depth. The Forest Reserve-Apex district consists of three elongated domes which expose the Naparima formation and between these are "saddles" of the overlying Moruga beds. The average inclination of the limbs of the anticlines varies from 15 degrees in the Parry Lands-Lot to 45 degrees in the Apex-Forest Reserve district. The distance from crest to trough is somewhat over a mile.

Folding of the Miocene sediments probably commenced during their deposition but was most intense during late Miocene and Pliocene. Upwarping of the beds began along what is at present the Southern Range as the thickness of Miocene deposits covering the underlying buried range was here at a minimum. Before Miocene deposition the older rocks had already been folded and faulted. In the upper Miocene sediments at Chatham Cliff (Fig. 25) there is a gravelly material containing cyclammina, orbitoids and chert pebbles and which has probably been derived by wave erosion of a mud volcano island such as that which appeared in Erin Bay in 1911. This mud volcano island was located along the extent of the southern fault zone in the Cedros peninsula.[5] The Chatham Cliff material seems to indicate that fracturing of the Miocene beds commenced at least as early as upper Miocene. The Southern Range has remained to the present a zone of structural weakness.

Factors which may have largely determined the character of the upper Tertiary structure in this part of the island are: (1) the buried range of older rocks underlying the Miocene deposits

[5] "Mud Volcano Island in Erin Bay," Trinidad and Tobago Govt. Council Paper No. 192 of 1911, page 3.

of the present Southern Range, (2) the rate of folding, and (3) the lithology of the Miocene sediments. The range of older rocks has localized the anticlinal folding of the beds along the Southern Range and by acting as a buttress has caused the beds to be closely folded and faulted over a wide area. Intense folding over a short period which did not permit a ready adjustment of the deformed beds together with the lithologic character of the sediments resulted in the development of closely compressed folds such as the Point Fortin and Los Bajos anticlines. The thick beds of clay in the Naparima formation, owing to their plasticity and oil content, during folding were squeezed up within the anticlinal crests, where they are much foliated and slickensided. The slickensided surfaces are usually covered with oil and the clay oil soaked. A thick sandy formation without clay members under the same degree of deformation would be more likely to form broad anticlines. The tightly folded clays and close folds suggest that deformation took place under little load.

MUD VOLCANOES AND MUD FLOW BRECCIAS.

The appearance, general distribution and probable cause of the mud volcanoes or "salses" of Trinidad has already been discussed by Cunningham-Craig [6] and by Wall and Sawkins.[7] The writer wishes here to emphasize (1) that the distribution of the mud volcanoes is largely limited to the area of outcrop of the complexly folded and faulted middle and lower Miocene beds of the Naparima formation which are exposed along the Southern Range, and (2) that in connection with the mud volcano activity there has, in places, been an extensive development of a mud flow clay breccia. The location of the important mud volcanoes in the part of the island described is shown in Fig. 25.

The clay breccias are black petroliferous clays in which are contained pebbles, fragments, and bowlders of the underlying rocks. Stratigraphically equivalent beds to those from which the

[6] E. H. Cunningham-Craig, "Oil Finding."

[7] "Memoirs of the British Geological Survey, "Report on the Geology of Trinidad," by G. P. Wall and J. G. Sawkins, pp. 149–156.

material in the breccia has been derived outcrop in part of the Southern Range and fragments of lower Eocene and Cretaceous rocks resemble beds of this age in the Central Range.

The clay breccia covers a considerable area along the extent of the southern fault zone. Where this zone of fracturing approaches the coast between Erin and Chagonary Points there is a large number of mud volcanoes and the character of the coastline has here been determined by the associated mud flow breccias. At Chagonary Point there is a large mud flow extending for about a quarter mile from a mud volcano to the sea. The small area of high ground, about 50 feet in elevation, which forms l'Islet Point is entirely made up of clay breccia and has at present several active mud volcanoes. L'Islet Point represents an old mud volcano islet which upon slight elevation of the land has become part of the main island. The mud flow breccias are present in places where there are now no mud volcanoes, but in areas along the southern fault zone, and it is likely that mud volcanoes have been in existence along this zone at least since upper Miocene time.

The presence of the mud volcanoes within the highly disturbed zone of the Southern Range indicates a genetic relation to folding and faulting and their distribution within the outcropping Oligocene beds or within the Naparima formation where the latter is of minimum thickness suggests that the mud volcanoes are formed by gases coming chiefly from the Oligocene and older beds.

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THE DIAGNOSTIC VALUE OF COLOR IN POLISHED SECTIONS.

A PRELIMINARY STATEMENT.

STERLING B. TALMAGE.

In examination of a polished section under the reflecting microscope, the first thing that strikes the eye is the contrasting appearance of the various minerals, due largely to differences of color. The first recorded examination of a polished section, by Berzelius one hundred and ten years ago, indicated that certain polished minerals could be distinguished by color differences, even without the microscope. Nearly twenty years ago William Campbell, who first realized the important possibilities presented by the study of ores in polished section under the microscope, recorded the colors of several minerals along with certain chemical tests; and in 1916 Dr. Joseph Murdoch, after several years of intensive study, offered the first publication on the subject that could lay claim to completeness. In Murdoch's determinative tables, color was the first diagnostic factor.

Murdoch's book was given much well deserved praise at the time of its publication, but soon there began to be heard complaints relative to the application of his methods by other men. It was claimed that Murdoch's color distinctions were too finely drawn to be of practical use. The only real ground for these complaints seemed to be that Murdoch had done his work too well; so well, in fact, that nobody could follow him. Several men who worked with Dr. Murdoch have expressed the opinion that his color distinctions, finely drawn though they were, were perfectly sound and determinative as far as was claimed for them, but that Murdoch was the only man whose eye for color was delicate enough to get the most out of these differences.

Further inquiry brings out the fact that it was not the superiority of Murdoch's eye so much as the superiority of his methods

that made the difference between his results and the results attained by others. Murdoch beveled or undercut all his standard specimens, so that by a double mounting any two specimens could be readily compared side by side in the same microscopic field. As he explains, his diagnostic color contrasts are uniformly based on this principle of comparison with an established standard. Most men are unwilling to devote to the preparation of the specimen the painstaking care that Murdoch found necessary in order to compare the various minerals edge to edge; moreover, such a method is limited in its application to minerals that are cut by the edge of the section, and so can be placed in contact with the standard. All attempts to apply Murdoch's color scheme without utilizing this principle of direct comparison have resulted in disappointment and dissatisfaction.

In 1920 Davy and Farnham issued another book on the subject, in which was announced the principle, based on four years' experience with Murdoch's tables, that " fine distinctions in color value between the many so-called white minerals cannot be depended upon as a safe property on which to base the major classifications in making identity determinations." Consequently they were led to present a scheme of identification described as " independent of color distinctions " and based primarily on a process of elimination through the application of a certain restricted chemical routine. The limitations of this procedure are evidenced by the fact that the authors urge " in most cases " a final recourse to the blowpipe, which, it is stated, " adds far more confidence to the determination."

The Davy and Farnham eliminative routine is perhaps based on sound principles, and is good as far as it goes, but it surely fails to go far enough if positive identification is the goal sought. For some minerals the identifications are positive and satisfying; but for many more, the completion of the routine tests leaves one far from sure as to what mineral he is examining. The objection to the blowpipe as final arbiter is in part the same as the objection to Murdoch's beveling scheme—it entails an effort that most men will not take the trouble to make. But the blowpiping

plan is subject to the further objection that most of the minerals whose identity is uncertain are present in small specks, or are intermixed with other minerals whose identity may or may not be established. In either event, the securing of a piece of the doubtful mineral, uncontaminated by other material and large enough for a blowpipe test, is often next to impossible. The statement by Davy and Farnham that "very often all the other minerals are known, and the reactions yielded by them can usually be discounted" has not stood the test of experience. In many cases the blowpipe tests may be truly determinative, and therefore helpful; but where the purity of the mineral concerned is open to question, one is often forced into the intolerable position of basing his ultimate criterion on blowpiping guesswork.

It would appear that Davy and Farnham, in their reaction against identification under the microscope being "pushed beyond its natural limits" went to the other extreme, and did not allow to color distinction the prominence that it deserved, nor get from it all the help that it could reasonably furnish. While Murdoch's color distinctions are as useless as ever to a man just beginning work in this line, or to one attempting to make his color memory take the place of direct comparison, many men who have done some studying from Davy and Farnham, and so have become acquainted with the limitations as well as with the good points of their scheme, are constantly referring to Murdoch's book in an effort to get farther than the later published scheme will take them. The more training a man gets in polished section work, the more does he appreciate the value of color distinctions.

In fact, after one has gained some experience in this line, he is gradually forced to the conclusion that, for most minerals, color is the surest and least variable criterion on which to base an identity determination. Some minerals, of course, show a color variation, due generally to variation in chemical composition. There is necessarily a limit to the fineness with which color distinctions can be made, and in some isomorphous series the intermediate members are not determinable in this way, or for that

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matter, in any other way short of a quantitative chemical analysis. Such variation in a few minerals is surely not enough to condemn the principle; in fact, if the variability is thoroughly understood, it may be used as a factor of determinative value rather than as an element of uncertainty.

Experience has demonstrated the fact, however, that *descriptions* of color are subject to nearly as many interpretations as there are interpreters, no one of whom may get near to the idea that the describer intended to convey. Likewise, descriptions of the same color by different investigators show variation. Take, for example, a fairly common mineral, pyrrhotite; its color is variously described as light bronze, cream, pale reddish yellow, pale creamy brown, bronze yellow, and pale brownish cream, but no one can know just what it looks like from any or all of these descriptions. When once a man has worked with it, the term "pyrrhotite color" conveys to his mind a very definite idea.

Consequently, the necessity for proper color standards must be emphasized as a prerequisite to definite accomplishment in the way of mineral determinations based on color differences. Work with the comparison microscope has demonstrated that few polished minerals have precisely the same color; even among the many minerals designated as *white* almost any two, side by side in the same field of view, will show a difference. These differences are often slight; though distinctly visible they are impossible of description in a way that will permit recognition of any described contrast at first sight. Full comprehension of these color differences is not subject to verbal transmission from man to man; they must be seen to be appreciated.

Murdoch's plan of undercutting the edges of each section is subject to two objections; the one, already stated, that the labor involved is more than most men will devote to the task; and another, more serious, is that the grinding of a section in such a way as to make the edge cut any doubtful mineral will frequently result in the destruction of a considerable part of the section. Both objections are overcome by the use of a comparison eyepiece and two microscope tubes.

The Two Tube Method.—This method permits the direct comparison of any two polished surfaces, whether in permanent or temporary mounts, and whether or not the minerals concerned are near the edge of the section. The eyepiece shows both surfaces under examination, each occupying half of the field; the two semicircular areas appear to be in perfectly sharp contact, and, after the illumination is once adjusted to precise uniformity, the

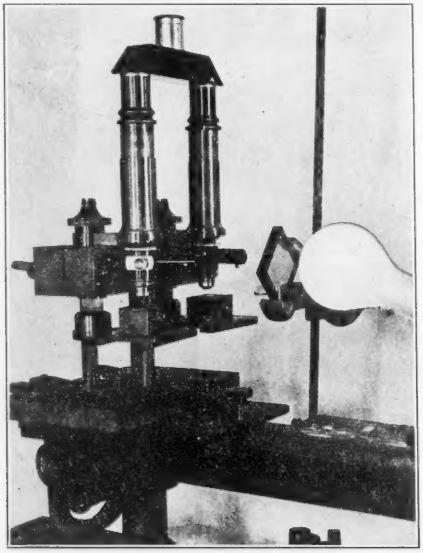

FIG. 27. Instrument for comparing colors of minerals.

manipulation is no more difficult than in working with a single instrument.

The most satisfactory arrangement consists of two fixed tubes, each with its own objective and reflecting illuminator. (See Fig. 27.) Focusing is accomplished by altering the level of either stage, as moving the tube to which the illuminator is attached would alter the lighting of one of the sections. Perfect uni-

formity of illumination is a prime necessity; this must be obtained by taking two sections of the same mineral—galena serves very well—and adjusting the light source and the reflectors until the appearance of the two halves of the single field, as viewed through the comparison eyepiece, is identical. Carefully paired objectives and reflectors are desirable. The plane mirror type of reflector has been found preferable to the prism type, as it gives a more uniform light. While the obtaining of perfect uniformity is a somewhat tedious process, the adjustment once made is permanent, if not disturbed.

It has been found that a satisfactory adjustment by daylight is not feasible, and from this there developed the fact that a really surprising color-range exists in so-called normal daylight. Reflection from different parts of the sky makes a decided difference in the appearance of polished sections of the same mineral, and the variation at different times of day is much greater than was supposed. The eye seems to adapt itself to those gradual changes in such a way that the variation while working by daylight is not troublesome; but certain daylight values when matched almost exactly by artificial light do not give good visual color values, as judged by the appearance of known minerals. After considerable experimenting, the best results have been obtained by the use of a Mazda 75-watt 115-volt blue ground-glass lamp, screened by Wratten filters Nos. 78*b* and 78*c*. This arrangement gives a light value well within the normal daylight range, and also gives good visual color values, minerals under this illumination looking just about as they do by daylight.

Some contrasts between different minerals are more marked with colored light than they are with white; for instance, the greenish tinge that distinguishes tennantite from tetrahedrite, described in detail later, is somewhat more evident in a light containing some excess of yellow than it is in a white light. It is possible that further study will indicate some other contrasts of diagnostic value that can be intensified by proper filtering.

Most men of normal vision can readily perceive such color

differences, but it is probable that very few men have sufficiently good color memory to enable them to use these differences in any other way than by direct comparison in the same field of view; moreover, many minerals look very different in different environments, especially by contrast with more strongly colored minerals. For instance, chalcopyrite, in a field of gray or white minerals, looks clear brass yellow; against pure native gold, the chalcopyrite appears a dirty olive green, and if adjacent to native copper, the chalcopyrite looks nearly grass-green. This is not due to any color difference in different specimens of chalcopyrite, for the comparison eyepiece shows that in all these specimens the chalcopyrite has precisely the same color, and that the difference is only apparent, due to the stronger colors masking or subduing the visual effect of the yellow rays. Such apparent variations may be valuable helps in identification.

There are several cases in which two minerals are so nearly alike, chemically as well as physically, that their differentiation is difficult. For instance, pyrite and marcasite have the same composition and the same behavior toward reagents, the same hardness and the same appearance under the microscope. But direct comparison shows that the pyrite is uniformly a little yellower than the marcasite, though the difference is so slight that only when the two minerals are side by side in the same field does one dare feel sure of it. In polarized light the isometric pyrite and the orthorhombic marcasite look very different indeed; this test was applied as a check on the color distinction, and in every case the diagnostic value of the difference in yellow color was reënforced rather than weakened.

Tennantite and tetrahedrite are another pair almost indistinguishable, but even here there is actually a color difference. Under the comparison microscope the tennantite shows a suggestion of blue, a difference so slight that one hesitates to give it diagnostic significance. But by comparing the two in turn with galena, the tennantite looks faintly olive green, while the tetrahedrite looks brown without the green suggestion.

Standardization of Color.—It has been assumed by many that

variations in description and appearance of minerals constituted a sufficient reason for relegating color distinctions to the background, but it is believed that by standardizing and studying such differences they can be made of real diagnostic value. It will be absolutely necessary to establish a better standard than verbal description. Murdoch tried to connect up his scheme with Ridgway's standard colors, but found the mineral tints nearly all so pale as to fall between white and the lightest shades on Ridgway's scale. Prof. Schneiderhöhn, the German scientist, has made a step in the right direction by tabulating the color values of about fifty minerals according to Ostwald's percentage scale. He describes his method as the using of a drawing ocular or camera lucida, by which a spot of colored light could be reflected from the mineral surface on to the white paper margin of a color chart. Another spot of light is reflected on to the adjacent colored portion of the chart; overlap is avoided by careful masking. According to his statement, the matching of the lighted portion of the color chart and the light spot colored by reflection from the polished mineral can be done with considerable accuracy. While it would be idle to condemn this scheme without a thorough trial, it seems that a comparison permitting actual view of the surface under study must be more satisfactory than the matching of a spot of reflected light on the margin of a colored paper chart, with all the complex precautions that would be necessary to avoid interference. To be really useful, moreover, the scheme should not be confined to a chosen fifty species, including several gangue minerals, but should include all the known opaque minerals; otherwise there is always the possibility of an unlisted mineral matching one in the table, thus permitting false identifications.

It has been noticed that different men, of supposedly normal vision, show a decided difference in sensitiveness to different colors, at least in so far as the mineral tints are concerned. This was evidenced by certain men being very quick to detect an excess of blue, while others were more sensitive to an excess of yellow. In experimenting with screens for the production of artificial daylight this personal equation was very marked. Natu-

rally, one's description of a faint color contrast would be modified by his personal sensitiveness; but in no case have two men disagreed as to whether the two halves of a field seen through the comparison eyepiece did or did not match perfectly. The difference seems to be not in detecting the slight contrasts, but merely in defining them, thereby emphasizing the need for some sort of an absolute color scale independent of description.

In laying the foundations for the establishment of such a scale, certain desiderata have been kept in mind. The standard colors should be of the same quality as the mineral colors, namely, bright reflections, rather than colors on paper or other rough surface. The color comparisons should be easy to make, with only a necessary minimum of time-consuming adjustments. If possible the colors used should be subject to some degree of gradation that can be expressed in numerical or some other absolute form.

Suggested Standards.—The search for such an ideal has not much more than begun, but already certain lines are indicated as offering considerable promise. The first possibility is a set of standard minerals, and at Harvard University where Dr. Murdoch's original set, in duplicate, is available, that method has already proved useful, and in many doubtful cases decisive. It is thought that this method may be extended beyond the room containing the Murdoch specimens by a careful selection of certain minerals as significant markers, the other minerals being graded as intermediate between these standards. The standard minerals should be species of constant color, and easy to procure; they should be so spaced in color differences as to subdivide the minerals between the standards into small groups, thereby permitting their differentiation by microchemical tests much more easily than is now possible. If only ten groups could be established with certainty among the hundred or more minerals that Murdoch called white, the certainty of determination would be greatly increased. Nearly fifty minerals come under Murdoch's heading of "galena white," yet probably not three of these have exactly the same color as galena. Moreover, galena itself is far from white when seen alongside a really white reflecting surface.

Schneiderhöhn lists galena as tinged with 33 per cent. of the third ultramarine blue on Ostwald's scale; and while this figure certainly appears too high for the blue content of the light reflected from galena, the blue appearance of this mineral when alongside a white reflecting surface, such as native tellurium, or arsenopyrite, or particularly the surface of a good mirror, is surprisingly evident.

Another line of investigation that shows some promise is the comparison of mineral surfaces with polished alloys. If the right colors can be obtained in alloys, of known composition and treatment so that they can be duplicated at will, such standards might be preferable to mineral standards, as there could be no danger of error through mistaken identification of a standard, the grading could be done more closely and especially more evenly, and perhaps the whole color scale could be mounted on a block small enough to go on the microscope stage. Experiments with alloys indicate that, in certain ranges such as the yellows and pinks, all the mineral colors may be duplicated; but in the blues and grays where added refinement is needed most, alloys of the proper color values have not yet been found.

The plan that at present seems to offer the best possibilities is the using of a truly white reflecting surface under one tube of the comparison microscope, and the mineral to be compared under the other tube. The best white surface so far known is a mercury mirror—a fragment of a high-grade looking glass—which gives a smooth and brilliant white reflection. If a colored screen is interposed between the reflecting illuminator and the source of light, the previously white mirror surface takes on the color given it by the screen. By using a color screen of graded intensity, any depth of color from the strongest desired down to the faintest visible tint may be given to the mirror surface. Preliminary experiments made with wedges of gelatine in various colors permitted the exact matching of several minerals; others could not be matched perfectly with the colors at hand. It is proposed to procure glass plates of the pure spectral colors and such other tints as may prove desirable, and grind these down to a wedge

shape with a disappearingly thin edge; by the use of a mirror surface, and the interposing of one or more of these wedges in a holder provided with a scale, it appears possible to duplicate any mineral color, and to express the result numerically instead of descriptively.

It is not expected that color-matching will permit definite identifications to be made in all cases without recourse to any other tests; it is hoped and confidently expected that, by systematizing this color-matching process, much can be done toward simplifying and adding to the certainty of mineral identification under the reflecting microscope. There are other lines along which this determinative work may be improved, notably a refinement of the scale of hardness. Also it would be well to get away from the routine application of chemical tests which leave one dependent on the blowpipe for final determination, and to develop if possible some tests to be applied within a particular small group of minerals, determined by color and hardness to begin with; such tests could be made with special reagents if necessary to make them really determinative and distinguishing. There seems to be no need for restricting the reagents used to the five or six that are needed most frequently, nor need we apply every reagent to every mineral as a matter of routine, if such routine tests fail to give information of value.

The chemical tests at present in use may be classed as positive, negative, and indefinite. A sharply positive reaction is the most satisfying, or a distinctly negative test may be of value; but such reactions as are described by the terms " faintly positive," " slight tarnish," " sometimes nearly negative," and so on, are worse than useless. Their character may be changed by differences in room temperature, or by a slight difference in concentration of the reagent. The same mineral sometimes reacts differently depending on whether it is perfectly or poorly polished. In the case of small grains, the influence of surrounding minerals may make a decided change in these faint reactions. Some of these indefinite tests seem to work on a damp day and fail to work when the air is dry; and for some reason not yet explained, two

men working side by side will sometimes try the same reagent on the same mineral, and report the result differently. These faint, uncertain and uninforming tests should be superseded, if possible, by other tests that can be definitely classed as positive or negative, instead of being so dependent on humidity, or room temperature, or a personal equation or other chance control. The fact that many reagents are but rarely used is no argument against having them available when needed. The rarer minerals are often the hardest to identify, but if informing tests can be applied to them the few extra bottles of special reagents, even if used only once in several weeks, will more than pay for themselves by time saved in doubtful cases.

In the final analysis, the determination of minerals in polished sections is not a proper end, but only a means to an end. Identification simply forms a background for interpretation; a very essential background to be sure, for if the identifications are uncertain the interpretations must be correspondingly open to question. Consequently, anything that makes the process of identification shorter or simpler or surer furnishes that much more time and opportunity for interpretative and productive study.

SUMMARY.

Color distinctions are desirable, and to a large degree reliable, indicators in mineral identification.

Many useful color distinctions are so delicate as to make it impossible to understand them from description alone.

The comparison microscope, or comparison eyepiece with two microscopes, is the best means of bringing out these color distinctions. Perfect uniformity of illumination is essential.

Color distinctions may serve either as the first step in a classification, such as Murdoch's, or as the final differentiating factor between two minerals otherwise alike.

The absolute color value of any opaque mineral is constant, except for a few minerals of variable composition; but the apparent color values of the same mineral may be very different in different environments.

Daylight is too variable to be used for these comparisons. A standardized artificial light near to daylight value is quite satisfactory.

Some color contrasts may be intensified by the interposition of colored screens.

Color standards expressible in scalar terms, and not dependent on description, appear to be necessary for further progress.

Standard minerals enable many identifications to be made by direct comparison alone.

Standard alloys may be useful in establishing a standard scale.

Wedge-shaped and scale-fitted color filters, to give graded artificial tints to a normally white reflecting surface, seem to offer the best promise.

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MAR 24 1925

AN APPARENT-DIP PROTRACTOR.

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A NUMBER of apparent-dip scales, charts and protractors of various types have been described during the last fifteen years; but all of them except one, as far as known to the present writer, are intended for the determination of the value of the angle of apparent-dip, rather than the angle itself. The exception is the protractor recently described by Gaby,[1] by means of which the angle of apparent-dip may readily be constructed, the value of the angle being of secondary consideration. The protractor described here is similar to this in purpose, but is somewhat simpler in both construction and use.

As shown in Fig. 28, this protractor is in the form of a 45° right triangle to which has been added a divided quadrant having its center at the vertex of the right angle and a side of the right triangle as its radius. The vertical side of the triangle is marked by a sine scale from the degree points of which converging lines have been drawn toward the opposite vertex. On the hypotenuse a 90° scale has been laid off, the divisions of this scale having been obtained by the intersection of the hypotenuse with radial degree lines from the divided quadrant. From these points vertical lines have been drawn to a series of corresponding points laid off on the base line of the triangle.

The construction of the protractor is such that all apparent-dip lines, as determined by means of it, will pass through the vertex of the right angle, thus permitting the use of a rotating arm for obtaining and plotting angles of apparent-dip. This arm, centered at the vertex of the right angle, is shown in the small diagram of Fig. 28, but not in the main figure, in order to

[1] Gaby, W. E., "Combination Dip-chart and Protractor," *Min. and Sci. Press*, vol. 123, p. 201, Aug. 6, 1921; also "A Slide-rule Dip Chart," *Mining and Metallurgy*, vol. 3, pp. 48–50, Sept., 1922.

avoid masking any of the features of the latter. The arm is of transparent material; it is marked lengthwise by a single line, and is long enough to intersect the divided quadrant on one side of the center and to extend for two or three inches beyond the center in the opposite direction.

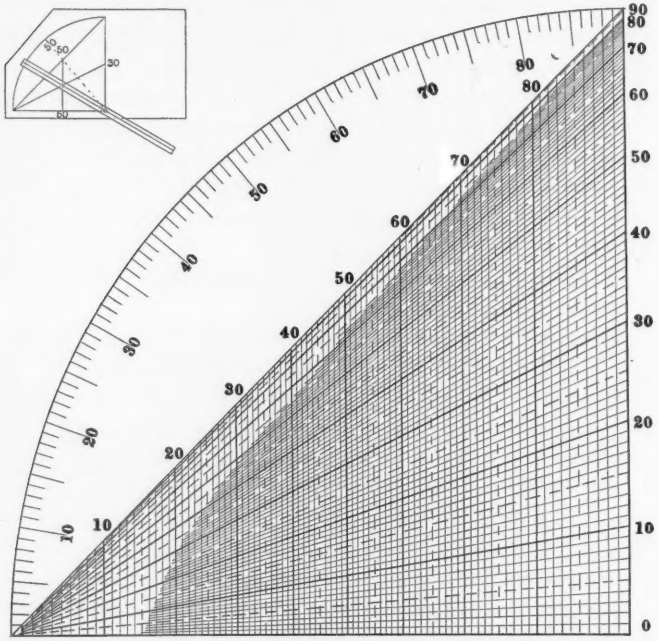

FIG. 28.

The vertical lines of the protractor represent true dip values, and the converging lines values of the direction angle (or angle between the direction of apparent-dip and the strike of the plane whose apparent-dip is sought). To obtain the apparent-dip when the true dip and direction angle are given, the protractor arm is set so that its line will pass through the point of intersection of the lines representing the given dip and direction angle respec-

tively. The arm will then make with the basal edge of the protractor the required angle of apparent-dip, and the intersection of the line of the arm with either the divided quadrant or the hypotenuse of the triangle will give the value of the angle. The small diagram of Fig. 28 illustrates the setting of the protractor arm for obtaining the angle of apparent-dip when the true dip is 50° and the direction angle 30°.

In plotting right-hand dips on geologic sections, the protractor is used like an ordinary arm protractor, its basal edge being brought into coincidence or parallelism with a horizontal line of the section, and the apparent-dip line being drawn along one edge of the previously set protractor arm. With left-hand dips, the position of the two parts with relation to the section is reversed, the arm being placed horizontally, and the apparent-dip line drawn along the basal edge of the protractor.[2]

The basis for the construction of this protractor is the trigonometric equation for apparent-dip, expressed in the form

$$\cot a = \frac{\cot c}{\sin A},$$

in which a is the apparent-dip, c the true dip, and A the direction angle. If, in a right triangle, the side adjacent to an acute angle is made equivalent to the cotangent of the angle of true dip, and the opposite side equivalent to the sine of the direction angle, then it is obvious from the above equation that the acute angle will be the angle of apparent-dip. Therefore, by making one side of a right angle a sine scale and the other side a cotangent scale, the general graphic solution may be obtained. Since, however, an ordinary cotangent scale is of infinite length, it is necessary, in order that the entire range of 90° may be represented in

[2] At least two other problems—the determination of the orientation and angle of dip of the line of intersection of two given intersecting planes, and the determination of the dip and strike of a plane when its apparent dip in two different directions is known—may readily be determined by means of the protractor here described, although in both instances the solution must be by a method of trial. In each of these problems a single setting of the protractor arm determines both dip and strike.

the protractor, to use, either wholly or at least in part, a cotangent scale and corresponding sine scales of varying unit length. In the protractor here described the entire cotangent scale—the base scale of the protractor—has been constructed in this manner, the unit of length varying uniformly from one end of the scale to the other. The unit length at any given point of the base line is the length of the vertical line at that point; and the length of the base line to the right of the given point is, in terms of this unit, the graphic cotangent of the angle shown by the scale reading for the point. The corresponding sine scale is, of course, given by the intersection of the vertical line by the converging diagonal lines of the protractor.

As an illustration of the above, in the small diagram of Fig. 28 the line drawn from the 50° point of the hypotenuse of the triangle to the vertex of the right angle makes with the base line an angle of 50°. If the perpendicular from the 50° point of the hypotenuse to the base line is assumed as the unit of length at this point, then the distance between the foot of the perpendicular (*i.e.*, the 50° point of the base line) and the vertex of the right angle must be equivalent to the cotangent of 50°. The diagonal 30° line intersects the perpendicular at the sine of 30°; and the line joining this point of intersection with the vertex of the right angle will therefore make with the base line, according to the equation given above, the angle of apparent-dip corresponding to a true dip of 50° and a direction angle of 30°.

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MOLYBDENITE DEPOSIT NEAR NEW ROSS, NOVA SCOTIA.[1]

CHAS. W. COOK.

SOME years since the writer was privileged to examine a large number of molybdenite deposits in the United States and Canada. These deposits are scattered over a very wide area and show a considerable number of variations in the nature of occurrence and the mineral associations of the molybdenite. Some of the deposits appear to tell a rather clear story of their origin and to afford data upon a subject about which comparatively little has been written. In the present paper, the writer intends to discuss an interesting occurrence near New Ross, Nova Scotia. The deposit is located about twenty-five miles from Windsor and four miles from New Ross, in Luneburg Co.

The country rock of the district is a coarse-grained to porphyritic muscovite granite. Both orthoclase and plagioclase are present, although the former predominates, and both are white in color. In some specimens considerable biotite is present.

This granite has been intruded by aplite dikes, which, in places, show a decidedly pegmatitic character. Neither the trend nor the magnitude of the molybdenite-bearing dike near New Ross can be definitely determined on account of the covering of glacial drift. According to Faribault,[2] these dikes in general have a north-south trend and the distribution of molybdenite-bearing boulders in the drift in the vicinity of the New Ross deposit suggests such a trend in this particular instance. However, it is not the purpose of this paper to discuss the magnitude of the deposit but rather to consider it from the standpoint of the information which it can contribute to the general question as to the origin of molybdenite deposits.

Three, if not four, definite stages in the formation of the deposit appear to be shown: First, the intrusion of the aplite;

[1] Society of Economic Geologists, New York Meeting, May, 1924.

[2] Personal communication.

second, the formation of the pegmatite; third, sericitization; and fourth, the deposition of the molybdenite and associated minerals commonly regarded as indicative of magmatic emanation action. That stages three and four can always be separated, may be questioned. However, at some places, the two are very distinct although they are probably closely related in time as will be pointed out later.

The aplite possesses a fine-grained granitoid texture and is pink in color. While both orthoclase and plagioclase are present, the orthoclase is much the more prominent of the two and gives the color to the rock. Muscovite is also present although sparingly.

The pegmatite is composed almost entirely of pink orthoclase and quartz and is therefore an alaskite. The quartz generally shows a decided bluish tinge. Commonly the quartz and orthoclase show a pronounced segregation in the pegmatite but at some places appear in about equal proportions.

That the pegmatite is later than the aplite is suggested: First, by the nature of the contact between the two; second, by the small inclusions of the aplite in the pegmatite; and third, by the orientation of the orthoclase crystals with respect to the contact. The contact is sharp and exceptionally well defined, except where it has been subjected to a subsequent action to be discussed later. Although the contact is irregular in outline, in some instances it has sufficient straightness to suggest the existence of fractures. The inclusions of the aplite exhibit this same sharpness of contact with the pegmatite. In some, the outline bears a close resemblance to that of the main contact as if they had been separated from the main mass by the intrusion of the alaskite magma or the force of crystallization of the orthoclase. The orthoclase crystals commonly show an orientation perpendicular to the contact.

The sericitization of the orthoclase appears to have occurred along fractures, probably formed as a result of contraction due to cooling. These fractures apparently were formed along lines of weakness such as at the contact of the aplite and the alaskite-

pegmatite, between the orthoclase and quartz of the pegmatite and along cleavage planes in the orthoclase.

As already stated it cannot be definitely established that sericitization preceded the deposition of the molybdenite in all cases. In fact there is considerable evidence that the two processes were going on at the same time. However, in many places where the molybdenite occurs along the cleavage planes in the orthoclase crystals of the alaskite-pegmatite, a thin film of what is apparently sericite may be observed between the orthoclase and the molybdenite. In some instances this micaceous material has a distinct yellow color which suggests the possibility of a molybdenum mica. It has not been possible either to prove or disprove this suggestion, since it has been impossible to obtain a sufficient quantity of the material, which was unquestionably free from contamination by the molybdenite, upon which to make an analysis.

The areas in which sericitization has been most pronounced generally show, in addition to the sericite, molybdenite, tourmaline, fluorite, and occasionally bornite. In some places vugs, several inches in diameter, filled with tourmaline and sericite occur. These two minerals are generally rather definitely segregated, with the bornite occurring only in the sericite while the molybdenite is disseminated through both the sericite and the tourmaline. Where sericitization has occurred at the contact of the aplite and pegmatite, the alteration of the aplite is quite pronounced in counterdistinction to the normally sharp contact mentioned above.

The molybdenite appears to show a preference for the orthoclase of the pegmatite and the sericitized contact of the aplite and pegmatite. While present in the quartz, it is present in much smaller quantities. In general the molybdenite occurs as very thin tabular crystals possessing a very high metallic luster.

The writer's interpretations of the above facts are as follows:

First. The granite country rock was intruded along the predominating line of weakness of the area by a magma from which the aplite crystallized.

Second. The pegmatite magma was injected into the aplite along the same general line of weakness. As a result of the segregation of the calcium in the aplite magma, the magma from which the pegmatite crystallized had the composition of an alaskite.

Third. The residuum of the original magma, representing a highly concentrated solution of water, tourmaline, fluorite, molybdenite, bornite, and probably silica, was injected along contacts between the aplite and pegmatite, between the quartz and orthoclase of the pegmatite, and along the cleavage planes in the orthoclase crystals of the pegmatite.

Fourth. This highly concentrated solution, heavily charged with mineralizers, attacked the feldspars, altering the orthoclase of the aplite and pegmatite to sericite (the plagioclase of the aplite shows even more intense alteration, probably to paragonite). Some of the sericite may have gone into solution.

Fifth. The removal of the water from the already highly concentrated solution (and perhaps in part a falling temperature) brought about the crystallization of the molybdenite, generally in close association with the orthoclase and sericite, and to a much less extent in fractures in the quartz. This function of the sericite in bringing about the precipitation of molybdenite (as well as other metallic sulphides), with which it is not infrequently associated, has not, in so far as the writer is aware, been suggested before.

Sixth. Finally the highly charged residuum was segregated into masses which on crystallizing produced the vugs of tourmaline and sericite containing small amounts of molybdenite and bornite. There is some evidence, although not conclusive, that the last substance to be deposited was quartz.

UNIVERSITY OF MICHIGAN,
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EDITORIAL

THE ROMANCE OF THE UNKNOWN IN THE PREPARATION OF GEOLOGICAL REPORTS.

A PERUSAL of the numerous reports which have appeared during the past thirty years, dealing with structural and economic geology, reveals, on the one hand, the wide divergence of opinion on the origin of land forms or of rock associations exposed at the surface, and, on the other hand, the attempted solution of problems whose nature may not be expected to be understood, even in part, until such time as the origin of the forms and rock associations at the surface has been appreciated.

A few examples may be cited by way of illustration. Thus, with regard to problems in the first group, there appears to be no consensus of opinion on the origin of surface conglomerates in regions of low rainfall; on the origin of the profiles characteristic of valleys either glaciated or but recently "deglaciated"; or of the forms of modern mountains and of intermontane valleys. Neither does there appear to be any consensus of opinion concerning the sequence of operations involved in the erosion of a stream channel; concerning the origin of the peculiar forms and rock associates of dikes, sills, and laccoliths; concerning the origin of the forms of batholiths and their method of growth; concerning the origin of the forms assumed by many igneous intrusives associated with certain rock groups; of the form and mineral composition of certain ore deposits, together with their general rock relations; of water levels in particular mining regions; of climatic cycles as told by the appearance of the soils and rocks of a region; nor the origin of many other phenomena manifested at, or near, the surface to-day.

In face of this apparent inability, on the part of geologists, to agree as to the sequence of events in these processes and mani-

festations, the speculations of able geologists may be noted concerning the internal composition of the earth, its temperature, and the physical conditions of its constituent materials, while as yet there is no clear conception of the physical and chemical processes involved at depths not exceeding twenty miles, nor whether the temperature recorded from deep bores is due to local relief of pressure or is representative of a general rise in temperature with progressive depth. Papers appear on magmatic differentiation, whereas the succession of the typical forms of igneous intrusives from the surface to the so-called "Zone of Flowage" has not been ascertained, although the material for the tabulation of such lies abundantly to hand. Lengthy papers are prepared on the genesis of ore deposits in regions quite inaccessible, whereas the faintest idea only is possessed of the peculiar activities involved in the transit, or transfer, of igneous rock and ore material, in the abyssal laboratories of the earth's crust. Problems such as these are discussed with the utmost seriousness, side by side with a tendency to ignore the silent and independent testimony of the surface exposures—silent, but nevertheless eloquent and invaluable. One such silent witness in many regions is the great Archaean Complex, which is not a mere chaotic assemblage of rocks, but a magnificent storehouse of the "end results" of well-ordered physical and chemical reactions, whose significance must be comprehended before the more recondite, but related, problem of the activities within the deep levels of the earth's crust can emerge from the stage of nebulous speculation.

It is not so much the recognition of the existence of recondite problems herewith enumerated which causes the research student to experience a feeling of surprise as it is the confidence with which speculation is advanced, especially in view of the poverty of real results thus obtained. This is indicated in part by the many ingenious but divergent conclusions reached by writers. There can be but one correct solution, and the statement of this would be found to be extremely simple. Indeed the research student distrusts and rejects inferences and speculations concerning the operation of natural laws almost in a direct ratio to the complexity or ingenuity of the explanation advanced.

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How then may be explained the apparent anomaly of the production of exact and able reports by geologists on the measurements of ore bodies; on the nature of the enclosing rocks; on the direction of, and the amount of movement along, the associated faults; on the peculiarities of the various mineral assemblages therein; on all these, together with other notes of an economic nature, but accompanied, in certain cases, with a sweeping generalization on ore genesis, based possibly on a few imperfect observations only in one area.

An analogy may perhaps be found in the mental attitude of philosophical and metaphysical writers who think exactly along certain lines, nevertheless whose speculations are fearfully and wonderfully unreal in other directions. As extreme types may be noted certain among the schoolmen, who would have been appalled at an inexactitude in syntax or logic, nevertheless who, in all seriousness, entered into disputations as to the exact number of angels who could execute the stately movements of a minuet on a needle point.

An analysis of these psychological peculiarities leads to conclusions somewhat unexpected.

The mind appears to be controlled, in great measure, by early beliefs and training. Independent intellects alone can free themselves from this heritage of ideas which have been fixed during an earlier and more impressionable stage.

A point which is closely related lies in the fact that the familiar surroundings of childhood and youth constitute the normal condition of things to man, however wonderful in reality these surroundings themselves may be, and he accepts, usually without protest, the explanations he received concerning them as a child or as a student. Failing that, he dismisses them from his mind as distasteful or as unimportant. An external stimulus is needed to excite his interest in them afresh. In the case of Darwin, Wallace, Dana, and others, this external stimulus was supplied by the "Geographical Excursion." In the case of many physicists and chemists, it is supplied by the "Intellectual Excursion," or the excursion into another branch of science not learned in youth.

In the third place, every scientist has aspirations, even if he never becomes inspired. Like Perseus, Lohengrin, or the Knights of the Round Table, he aspires to leave the world a little better than he found it. Unknown to his conscious mind is the desire to "Overcome" and to be placed by Father Zeus himself among the Immortals in the skies eternal. Nevertheless, without some powerful stimulus such as the "Intellectual Excursion," he would have no grand new ideal around which to build wisely, and he would soon tire and fall into his early childhood habit of building "Castles in the Air" as a relief from the dull grind of routine work which appears to bring no lustre to his name. Then comes unbidden the old childish instinct to possess something which has not been earned. Hence the usual speculation not worthy of the conscientious and painstaking worker.

Dante was unable to enjoy properly the glorious environment of his native Italy, and, in the "Divine Comedy," he built a new world closer to his own desire. Milton saw the dull and commonplace in his fellows, and from his consciousness he evolved a world to fit his own ideal. Yet each succeeded only in foisting colossal fables on humanity, at the same time that each could have accomplished wonders for humanity had he but studied the truth at his very door. Newton, on the other hand, attempted to follow where the truth led him in nature, and the world has been the richer ever since for his humility of mind and his abhorrence of the "Get Rich Quickly" methods in the world of intellect and culture.

Nevertheless, there is no need for this flight from fact, for, did man but know it, those familiar surroundings which appear to be so drab in tone, so dull and commonplace, are really vibrating with romance to the antipodean. "Distance lends enchantment." The Canadian may not appreciate fully the significance of the arrangement of his Archæan Complex. He may long for the inspiration of the geology of the coral reef regions. On the other hand, the coal or water geologist of Australia, working in the subhorizontal shales and sandstones of his lowlands, longs for the inspiration of the Alps or the Himalaya, and he finds himself

envious of the geologists privileged to work among the Canadian schists, among the ore deposits in Europe, or among those associated with the Cordilleran batholiths of America.

The light came to Darwin, Wallace, Dana, Lyell, and others, such as our leaders in structural and economic geology through the "Intellectual Excursion" in new lands, and in new surroundings. They passed from their normal surroundings to abnormal ones, where the external stimulus was powerful, and where they were not hampered by early training and prejudices. These men had the open mind, for they were possessed of the spirit of humility, and they sought not, as Milton and Dante had done, to substitute magnificent phrases for truth. They sought rather to give a correct representation of the facts. These men thus had no need for recourse to "Castle Building in the Air" wherewith to give the requisite touch of romance to their writings; they sought not their own advancement; neither did they seek to protect their ideas with patent rights, but gave their best ideas to the world spontaneously, as a bird pours forth its song. They felt no longing for the "winged sandals" of the Heroes, nevertheless, all unknown to them, Pallas Athene saw that they were properly equipped, and directed their footsteps to the happy vales where they gathered the golden apples of the Hesperides which came to their hands. Thus they attained to immortality without seeking it, and even without knowing it, and the story of truth they told was more romantic than the fiction of Dante and Milton.

It is a comforting and consoling thought that the majority of economic geologists also have the mental equipment requisite for real greatness. The magnificent contributions by economic geologists which may be found in the pages of "The Genesis of Ore Deposits," 1902 (*Trans. Am. Inst. Min. Engineers*), and in related publications such as the journal ECONOMIC GEOLOGY itself emphasize this fact strongly. These papers, however, were, and are, attempts merely to correlate a great number of observed facts, and very little of speculative matter was included. All that appears necessary to achieve that greatness is to correct early prejudices by the "Geographical" or the "Intellectual Excursion";

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to recognize the danger of constructing "Castles in the Air"; to cultivate the scientific use of the imagination with humility of mind; to crave no patent rights, neither material nor intellectual; and then immortality doubtless will come unbidden, as it did to the great adventurers in the world of intellect whose memories are cherished and revered increasingly by mankind with the passage of the centuries.

E. C. ANDREWS.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE ORIGIN OF SEDIMENTARY IRON-ORES.

Sir: The interesting editorial by Professor C. K. Leith in your issue of June–July, 1924, broaches a subject of geological importance which though frequently discussed from a theoretical standpoint has been rather neglected by the practical geologist.

The article is written as though with one conclusion in view, yet it ends without a statement of that conclusion. After emphasizing the great thickness and extent of certain iron formations of various parts of the world and pointing out that at the present day owing to oxidation at the surface " iron is being removed in solution to a less extent than any other element with the exception of aluminium," Professor Leith says: " It will be noted that the principal difficulties to be encountered (in explaining the iron formations) relate to the source of such large amounts of iron salts, and to the transport processes which are able to segregate them so thoroughly, and not to the manner of precipitation from solution after they have been brought together."

Professor Leith has studied this question so thoroughly in its different aspects that it is improbable that he has not considered and found unsatisfactory the answer which presents itself to the writer.

Ferrous carbonate is soluble to a considerable extent at ordinary temperatures in water in the presence of excess of carbon dioxide.[1] If therefore it can be shown that there are reasonable grounds for believing that at the time the rocks were formed the atmosphere consisted of carbon dioxide and nitrogen and was

[1] 1000 c.c. of water under pressure of 2 atmospheres of CO_2 dissolves over 6 grams of $FeCO_3$. Seidell, A., " Solubilities of Inorganic and Organic Substances," p. 336, London & New York, 1920.

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devoid of oxygen, the difficulty in explaining the transportation disappears.

The quantity of oxygen in the air must have varied considerably throughout geological time, since it is dependent chiefly upon two mutually variable factors: (*a*) the rate of generation by vegetation in sunlight, (*b*) the rate of absorption by the oxidation of ferrous salts and carbonaceous matter. These two factors are in turn affected by such influences as climate, the relative areas of land and sea, the rate of denudation, the relative importance of vegetable and animal life, etc. The result has probably been an increase in the quantity of free oxygen, but the change may not have been continuously in the same direction.

Assuming that the atmosphere in early geological times was composed of a mixture of nitrogen and carbon dioxide, while the seas were saturated with the latter gas and held ferrous and other salts in solution, the oxygen produced by the primitive vegetable organisms existing in such a sea would first be absorbed in the oxidation and precipitation of the dissolved iron salts, replenished from time to time by the rivers. The conspicuous banding of the iron formations, which are such characteristic members of the pre-Cambrian in every continent of the globe, probably indicates that the process was in some way intermittent and recurrent.

The idea that the oxygen of the atmosphere is wholly of organic origin has been advocated and disputed by many writers.[2] The question can be settled only by geological evidence, but since it has an important bearing on this and other questions relating mainly to the pre-Cambrian, it may not be out of place to summarize here some of the evidence in favor of the view.

Carbon dioxide is evolved from volcanoes in large quantities; oxygen has not been detected for certain issuing from them. It is difficult to imagine a cosmogonic process which would produce by inorganic agencies an atmosphere of oxygen and yet retain

[2] For a summary of this discussion see F. W. Clarke, "Data of Geochemistry," pp. 53–57, U. S. Geol. Surv., Bulletin No. 616, 1916.

the iron in all known igneous rocks of the earth's crust in a state of incomplete oxidation.

The free carbon in the lithosphere is estimated as being chemically equivalent to many times as much oxygen as there is in the atmosphere.

The remarkable extent to which the carbonate radical has replaced silica in both basic and acid rocks in the Archaean is usually ascribed to metamorphism, but may perhaps be more easily explained as a superficial change at the time of deposition of the rocks.

It is to be hoped that the study of the geological history of the atmosphere will prove of value in correlating the strata, particularly of the pre-Cambrian, in widely separated parts of the world. It may be possible to recognize certain types of sediments as indicative of certain world-wide atmospheric conditions.

Two examples may be given of geological episodes which were perhaps conditioned by changes in the composition of the atmosphere. The incoming of the Cambrian with its very diversified fauna of calcareous-shelled animals marks the occasion when the carbon dioxide dissolved in the oceans was reduced in concentration sufficiently to permit of calcium carbonate remaining undissolved. The unfossiliferous pre-Cambrian limestones may have been thrown down from a saturated solution of bicarbonate.

The development of a dry land fauna with both insects and vertebrates may have been rendered possible by the oxygen produced by the first land floras.

A. M. MACGREGOR.

SALISBURY,
SOUTHERN RHODESIA.

MAGNESITE DEPOSITS AND THEIR ORIGIN.

Sir: Mr. George W. Bain has contributed a valuable article on Magnesite in the August (1924) number of ECONOMIC GEOLOGY. In regard to one little item, namely the silica in magnesite derived from serpentine, attention may be called to the occurrence

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of the silica as crystalline quartz in some deposits. Mr. Bain states that "The magnesium carbonate is deposited in veins and the silica carried away in solution. Some slight amount of silica is deposited as opal."

Hess [1] states that "The silica is carried away in solution by the water and is often deposited in other veins or with magnesite as opal or quartz."

The magnesite deposits on East Austin creek in Sonoma county, California, have been described by Hess [1] and Gale.[2] The latter in describing the deposits two miles north of the camp of the Sonoma Magnesite Company, states that "the mass is irregularly broken or jointed and filled with seams and cavities lined with silica."

In investigating this deposit in 1923, after considerable mining had been done, Gale's description was confirmed and I found that the silica was deposited in cracks and cavities as transparent crystalline quartz. This would indicate that, after the deposition of the magnesite, cracks and cavities had formed and the silica deposited later. Nevertheless this silica presumably came from the same waters that formed the magnesite deposit. The Sonoma deposit is now being operated. Several analyses of the magnesite were made, one of which contained an abnormal content of silica, the average of the East Austin creek deposits being much lower in silica. This analysis is given herewith. The magnesite is not discolored with iron oxide and the iron is presumably present as $FeCO_3$. Using Clarke's [3] latest table of atomic weights and assuming that all of the ignition is CO_2, the mineral composition is also given.

ANALYSIS OF MAGNESITE FROM THE UPPER EAST AUSTIN CREEK DEPOSIT—BY CURTIS AND TOMPKINS, OF SAN FRANCISCO.

SiO_2	18.30	Silica (chiefly quartz)	18.30
Iron oxide and Al_2O_3	1.01	Alumina	0.18
CaO	0.03	Iron carbonate	0.83
MgO	38.40	Calcium carbonate	0.06
Ignition	42.26	Magnesium carbonate	80.31
	100.00		99.68

SAN FRANCISCO, CAL. H. W. TURNER.

[1] Hess, Bull. 355, U. S. G. S.
[2] Gale, Bull. 540–S, U. S. G. S.
[3] Clarke, Bull. 695, U. S. G. S.

SHARING OF DRILLING INFORMATION BY OIL COMPANIES.

Sir: In several instances during the last year I have had rather forcibly brought to my attention a misconception which seems to be prevalent among many geologists who are not intimately associated with the methods and activities of oil companies. There is an impression that the geological information of the companies is carefully guarded under lock and key. One of our most noted colleagues from the East was recently very much surprised to learn that we freely exchange the logs or records of holes drilled for oil.

Very seldom do the major companies refuse to give out drilling information. Records of wells are freely interchanged. Even during the actual drilling of a hole, most of us are ready to tell at what depths we have reached the top or bottom of recognized formations. Many companies take solid cores of formations which are thought to have a practical value, either for purposes of correlation, or for "seating a string of pipe," or for other reasons, and often, after these cores have been seen by the geologist of the company drilling the well, they are shared with other companies.

The old excuse given by a company secreting its information used to be that it had been put to so much expense in gathering the data that it could not afford to distribute the same. Gradually the companies came to learn that by exchanging information each could gain a great deal more than it could obtain by working independently. I think that there are now very few oil company executives or oil geologists who would not agree to distributing the plain scientific data secured in their business, although occasionally they would reserve certain facts for a short time. On the other hand, they rarely give out their own interpretation of these facts. This is left for the other man to work out for himself.

F. H. LAHEE.

DALLAS, TEXAS,
NOVEMBER, 1924.

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REVIEWS

Gypsum: Its Occurrence, Origin, Technology and Uses, with Special Chapters Devoted to Gypsum in Iowa. By FRANK A. WILDER. Iowa Geological Survey, vol. XXVIII, pp. 47–558 (1923?).

The scope of this volume is clearly indicated by its title. Chapter I., of 16 pages, is devoted to the physical and chemical properties of gypsum. Chapter II., of 31 pages, describes the important deposits of gypsum in the United States and in foreign countries. The descriptions are brief and are confined chiefly to deposits that have been worked. As gypsum is a common mineral whose utilization depends largely upon proximity to markets there are undoubtedly many large deposits of this material that are not recorded in this chapter. Chapter III., of 21 pages, discusses the origin of gypsum deposits.

The author classifies gypsum deposits genetically as follows:

1. Deposits formed directly by the evaporation of sea water. Generally disseminated and seldom of economic importance.
2. Concentrations, accomplished by moving waters, of gypsum disseminated through sediments.
3. Deposits formed by alteration of other minerals, such as carbonates or anhydrite.

The formation of extensive deposits of gypsum by direct precipitation from sea water, although admittedly possible, is regarded as improbable. Most of the important gypsum deposits are believed by Wilder to have been formed by processes of concentration or alteration. Deposits classed under (2) apparently include those in which gypsum after being dissolved from gypsiferous sediments is precipitated in enclosed basins.

Chapters IV. and V. are devoted to the general description and stratigraphy of the Iowa gypsum areas.

The remainder of the book, about two thirds of the whole, is devoted to the technology of gypsum and to most readers will probably be the more interesting portion. To those who have not been closely in touch with the gypsum industry this carefully compiled and well illustrated account of the various uses of gypsum products will be a revelation. A bibliography of about 65 pages completes the volume.

Although it can scarcely be said that the report adds greatly to our knowledge of the mode of formation of gypsum deposits it is a thorough, well-prepared handbook that treats adequately most aspects of an interesting mineral industry.

F. L. RANSOME.

Slate in 1923. By G. F. Loughlin and A. T. Coons. Mineral Resources of the United States, 1923, Part II; pp. 49–61, figs. 3, Washington, 1923; U. S. Geological Survey.

Today slate, whether as roofing, granules, or structural slabs, meets intense competition by stone, tile, asbestos, and felt. The latter products are favored by the more localized production of slate—Pennsylvania, Vermont, New York, and Maine being, in order of importance, the main slate quarrying states. For examples, shipments of roofing slate west of the Mississippi or south of the Ohio river compete unfavorably with locally made composition roofing.

Further, during the war slate quarrying, not appreciably inflated by increased consumption, lost laborers to more remunerative industries. Slate splitting no longer attracts youths; at full wages, it is too costly to train older workmen. The supply of skilled slate splitters thus steadily diminishes.

Nevertheless, the slate industry, by establishing trade associations and laborers' schools, and diversifying its products, is regaining lost ground. In 1923 slate sold in the United States was valued at twelve million dollars—twice the sum in 1919. Sixteen new companies in 1923 increased the total to 120. Prices mounted: the quantity of slate rose 19.6 per cent. over that in 1922, while the value increase was 31.6 per cent.

The few pages reviewed are an illustration of the great value of publications like Mineral Resources. It is a mistake to permit retrenchment in such fundamental lines of government-subsidized research.

Chas. H. Behre, Jr.

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SCIENTIFIC NOTES AND NEWS

F. L. Ransome, professor of economic geology at the University of Arizona, Tucson, Arizona, has been elected a corresponding member of the Geological Society of Belgium, in recognition of his work in geology.

K. C. Heald has resigned from the U. S. Geological Survey with which he has been associated since 1909, effective immediately, and from Yale University, effective at the end of the academic year, to become associated with the Gulf Oil Corporation with headquarters at Pittsburgh, Pa.

Wallace E. Pratt, who has served the Humble Oil and Refining Company in the capacity of Chief Geologist since 1918, was elected to the Board of Directors at the Annual Meeting of the stockholders at Houston, Texas, on February 16.

C. K. Leith, of the University of Wisconsin, delivered three lectures on subjects pertaining to Economic, Structural and Metamorphic Geology before the Geology Club of the State University of Iowa on January 15 and 16.

Cyril W. Knight, former associate Provincial Geologist of Ontario, was recently awarded the Bigsby medal by the London Geological Society.

C. E. Dobbin, of the U. S. Geological Survey, is on furlough for five months in Panama for geologic work with an oil company. His address is Box 2003, Ancon, Canal Zone.

John Penberthy, formerly with the Shannon Copper Company and the Moctezuma Copper Company, has been appointed by the State Tax Commission to investigate technical problems in the suit of the United Verde Extension Mining Company in protest against the valuation placed on its property by the State Tax Commission.

C. A. Baird is in Maracaibo, Venezuela, where he has joined the geological staff of the Venezuela Gulf Oil Company.

A. C. Terrill, for the last four years professor of mining engineering at Pei Yang University, Tientsin, China, has returned to California, where he is now lecturer in geology at the California Institute of Technology, Pasadena.

J. B. Eby has resigned from the U. S. Geological Survey.

W. T. Thom, Jr., of the U. S. Geological Survey, has been compiling a structure map of the northeast quarter of the state of Oklahoma, in cooperation with the State Survey.

At the annual meeting of the Association of American State Geologists held in Ithaca, December 29 to 31, the following officers were elected for 1925: President, Wilbur A. Nelson of Tennessee; Secretary, M. M. Leighton of Illinois; Member of Executive Committee, E. W. Mathews, of Maryland. The Association voted to send a memorial to the President of the United States requesting a liberal support to scientific work. The memorial was presented in person by the new president of the Association and was favorably received.